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ABSTRACT

This comprehensive guide to the teaching of nuclear science at the secondary level includes recommendations on teaching methods, course and laboratory objectives, textbooks, audiovisual aids, laboratory equipment and experiments, and safety precautions. (MH)

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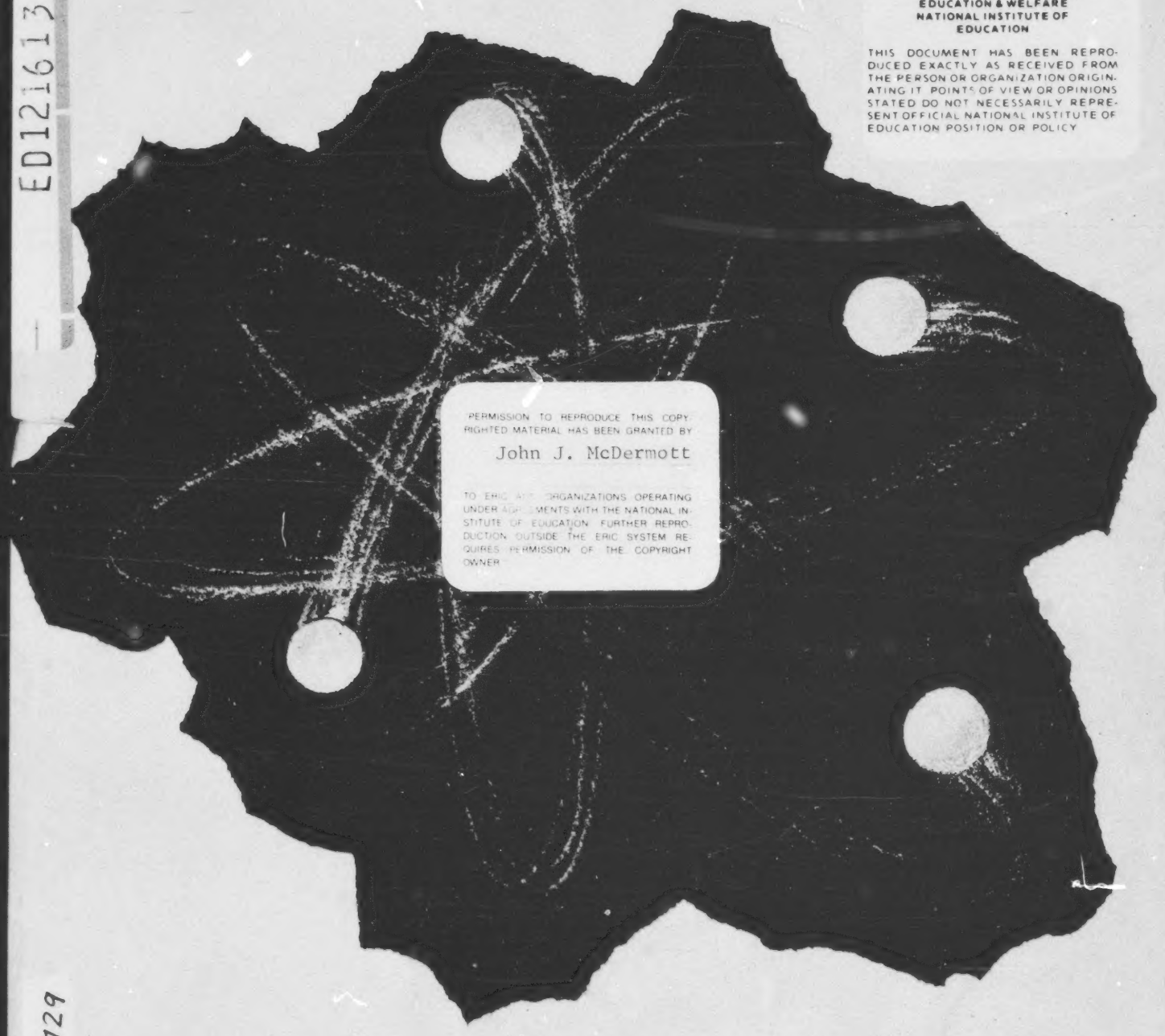

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Nuclear Science

A High School Course

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Introduction

This is a report of approximately eight years of work, thought, and experimentation concerning the introduction of a course entitled Nuclear Science into the high school curriculum. The course is designed to provide a basic but comprehensive understanding of the atom in the light of modern knowledge. Special attention is paid to the use of the energy of the atom as a contributive factor to modern civilization. This course crosses what are considered the normal disciplines of science, entering into the three basic fields quite freely. It was decided to present this material in a basic fashion, with projections in depth being attempted when deemed advisable by the relative importance of the material, and by class comprehension and interest.

It is hoped that the student will develop an appreciation of the basic units of matter and energy and in this way attain greater insight into the physical sciences and their relationships with the biological sciences. The concept of the interrelationship of mass and energy will provide a basis for better comprehension of modern physics and chemistry, while the uses of radioisotopes as biological tracers will illustrate their importance in modern research and emphasize the continuity of scientific knowledge and methods from one discipline to another.

This course is designed to develop student appreciation of the problems which confront our civilization, such as nuclear disarmament, the health problems of the Atomic Age, and survival in a nuclear war. The course will also show how man attempts to harness the tremendous energy liberated through fission and fusion reactions to provide the power necessary for the civilization of the future.

I LABORATORY SAFETY
AND
HEALTH PHYSICS

With the general lack of knowledge concerning radioisotopes and the unfounded apprehension generated by the word radioactivity, the question of safety will automatically arise with the discussion of initiating a course in which these substances are used. This question was answered quite satisfactorily in a special meeting held by the Board of Education of the City of New York. The conference was attended by the members of the Board, Science Supervisors, Radiologists, Teachers, and representatives of the United States Atomic Energy Commission. The following comments are representative:

> "....No health hazard is involved (to the student or teacher) in carrying out laboratory experiments with radioactive Iodine-131 and Phosphorus-32 in amounts not exceeding ten microcuries."[1]

> "A watch with a luminous dial contains approximately 0.5 microcuries of Radium-226. Therefore, staying for two hours in the vicinity of ten microcuries of Iodine-131, in a closed glass container of sufficient thickness to absorb the beta radiation, (about 2mm) is roughly equivalent to wearing a luminous dial watch for twelve hours. Obviously, the exposure

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[1]Board of Education, City of New York, High School Division Report of Meeting to Consider the Safe Handling of Radioisotopes I^{131} and P^{32} in Ten Microcuries Lots, February 6, 1953 revised October, 1958.

> accumulated by the student or teacher in one year would be very much less than that accumulated by a person normally wearing a Radium luminous dial watch."[2]

The question generally arises about the danger of spilling radioactive substances on the skin or clothing. Students should wear a long laboratory coat, rubber gloves, and a rubber laboratory apron when handling unsealed radioactive materials. Then, should a spill occur, the contaminated piece of apparel could easily be removed and laundered to remove the contamination. Even though these precautions are recommended, they are not entirely necessary. A ten microcurie spill of a beta emitter on clothing, disregarding the absorption of the activity by the cloth, would cause a dose rate in the germinal layer of the epidermis approximately equal to six Rads per hour. At this rate, the contaminated clothing would have to remain in close contact with the skin for a period of ten days to one month (a quite unlikely condition) to produce a temporary reddening of the skin resembling sunburn.

> "If a student or teacher drank all the solution containing ten microcuries of Iodine-131 no noticeable harm would result. Even larger amounts are given patients for a thyroid function test. The accidental ingestion of ten microcuries of Phosphorus-32 can also be considered harmless."[3]

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[2]Board of Education, City of New York, High School Division Report of Meeting to Consider the Safe Handling of Radioisotopes I^{131} and P^{32} in Ten Microcurie Lots, February 6, 1953 revised October, 1958.

[3]Ibid.

It is well to note here that we have been considering only two radioisotopes, Phosphorus-32 and Iodine-131. The above decisions cover all the isotopes available under general Atomic Energy Commission licensing. However, special care should be taken to avoid ingestion or inhalation of alpha emitters, since their high specific ionization may cause more internal cellular damage than a beta emitter which will have a lower specific ionization.

> "In this connection, it is well to emphasize the fundamental principle of radiation protection that unnecessary exposure to ionizing radiation should always be avoided. Therefore, care should be exercised to avoid any ingestion or inhalation of radioactive material."[4]

> "That radioactive material be handled with the same care usually afforded corrosive acids is certainly sufficient to insure safety."[5]

Of course, the learning of proper handling techniques with radioisotopes should be part and parcel of the training afforded by the laboratory experiments. Some of the students who are receiving their initial experience with radioactive materials may continue in this field, and bad habits acquired in the handling of small amounts of radioactive substances might be quite difficult to overcome if the need to handle larger amounts should arise later.

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[4]Board of Education, City of New York, High School Division Report of Meeting to Consider the Safe Handling of Radioisotopes I^{131} and P^{32} in Ten Microcurie Lots, February 6, 1953 revised October, 1958.

[5]Ibid.

In order to insure safety in the laboratory, a definite set of safety rules should be adopted by the instructor. A copy of these rules should be given to each student to learn, and he should be tested concerning them before he is allowed to work in the laboratory. Another copy should be prominently posted in the laboratory. Any person who breaks these rules should be seriously reprimanded. The rules enforced in this laboratory should be the following:

A. All possible precautions must be taken in order to prevent inhalation, ingestion or skin contact with radioisotopes. Therefore, the following rules will be in effect:

1. There will be no eating, drinking or smoking in this laboratory.

2. Keep your hands away from your mouth, nostrils and eyes.

3. All work with unsealed sources must be done in the fiberglass work trays. These trays will be lined with non-absorbent paper to retain spills and facilitate decontamination.

4. Laboratory coats must be worn at all times when working in this laboratory.

5. Rubber gloves will be worn at all times when handling unsealed solutions. These gloves must be monitored, washed with detergent and water, remonitored, and rewashed if contaminated before removal. The hands will then be washed and monitored.

6. Signs indicating radioactivity must be in prominent display during any experiment with unsealed sources.

7. All contaminated materials must be plainly labeled.

8. Radioactive waste will be placed in the plainly marked "hot" waste can. No other type of waste will be placed in this can, and no radioactive materials will be disposed of elsewhere.

9. The instructor will be consulted before any radioisotopes may be disposed of, to insure proper disposal.

10. There must be no pipetting by mouth. A propipetter or hypodermic syringe should be used.

11. All spills must be reported immediately, and decontamination procedures initiated under immediate supervision of the instructor.

12. All radioactive sources must be sealed before handling or counting.

If rules similar to this are inaugurated and enforced, there should be complete safety from contamination in the laboratory, barring human error.

Contamination of the equipment, the furniture, and the laboratory itself must be avoided in order to prevent the contamination of other students, and to prevent raising the background count in the laboratory to the extent that it interferes with the proper functioning of the sensitive Geiger-Muller counters. In order to achieve this, the teacher must be familiar with the general rules of radioisotope safety techniques.

All work with unsealed radioisotopes should be done in nonporous trays of a chemically inert substance, such as fiberglass or heat-resistant plastic. The tray should be lined with non-absorbent paper. Any material spilled on the paper can then be rolled up and properly disposed. Any material spilled on other surfaces should be blotted, the

surface scrubbed with detergent and water, dried, monitored, and rescrubbed if necessary to remove the contamination. The scrubbing and monitoring should be continued until no trace of activity remains. Of course, the activity of the isotopes used in a high school laboratory is so low that decontamination is a rather simple matter.

> "....Decontamination is considered complete when radioactivity from radioisotope groups I and II is not in excess of one millirep per hour average as measured in a small volume of air above any two square inch area. This corresponds to approximately one thousand counts per minute when a Geiger counter is placed as close as possible to the contaminated area... Note that in many high school experiments the actual counting rate will not greatly exceed that which meets the A.E.C. definition of uncontaminated."[6]

A clearly marked radioactive waste can should be available for the deposition of all contaminated materials. A twenty gallon covered trash can is quite suitable for this purpose. The container should not be emptied with uncontaminated trash, but should be subject to special handling. The paper can be safely incinerated, thus dissipating the activity, while the other material can be buried. Another method is to store the can and its contents for a one year period. At the end of this period, the activity will be reduced by normal radioactive decay.

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[6]Miner et. al. Teaching With Radioisotopes, U.S.A.E.C. Washington, D. C., 1959.

Small animal carcasses contaminated with radioactivity should be placed in glass containers and buried. The containers will prevent the carcasses from being dug up and scattered by foraging animals.

Isotope solutions of the low activity which would be used in the high school laboratory may safely be flushed down the sink. If the tap is allowed to run for five minutes previous to pouring the isotope and twenty minutes after, the activity will be so diluted as to be practically undetectable. It would be well for each individual teacher to contact his local health or civil defense authorities concerning this matter.

Any vaporization or sample drying of radioactive material should be done in a hood to prevent the inhalation of radioisotopes.

All laboratory glassware used for radioactive material should be rinsed, washed with detergent, and stored separately from non-contaminated glassware.

The supply of radioisotopes should be stored in a plainly labeled, locked metal container. A metal chest lined with cinder brick has proven to be quite satisfactory for this purpose. The cinder brick acts as a protective shielding, and also gives the box sufficient weight to prevent its being moved.

In order to prevent careless handling, all contaminated substances should be clearly marked with warning tape.

During the laboratory period, one student should be assigned as laboratory safety officer, whose duty would be the constant monitoring

of the laboratory for spills or any other contamination. He should immediately report any spills and aid in decontamination procedures. This will also, by the way, aid in teaching proper safety techniques. The instructions for the safety officer will be found with the experiments.

At this point it should be reiterated that radioisotopes used in conjunction with the proper safety precautions are no more dangerous than the corrosive acids which are used as a routine part of every high school chemistry course.

II SOURCES OF RADIOISOTOPES: LICENSING

On June 14, 1946, an article appeared in Science announcing that reactor radioisotopes were available from government agencies. On August 2, 1946 the initial shipment, a small amount of Carbon-14, was sent to the Barnard Cancer Hospital in St. Louis, Missouri.

By 1959, the Atomic Energy Commission had issued licenses to 2,555 institutions for use in medical applications, 16,000 to individual companies, and 1,562 to research groups.

> "Figures from Oak Ridge National Laboratory show a rise from 14,162 shipments of a total of 166,629 curies[7] in 1957, to 14,131 shipments of 228,714 curies in the next year, and 12,028 shipments of a total of 222,708 curies in the current year ended November 30, 1959. The shipments do not include those of retail suppliers which approximate 1,000,000 shipments per year."[8]

On January 11, 1956, the Commission made available to the general public small amounts of radioactive materials. Consider the quote from the following:

> Appendix B - "Licensing of Byproduct Material"
> Excerpt from Title, Part 30, Federal Register, Vol. 21, Part 6, January 11, 1956.

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[7] A curie is the number of radioactive disintegrations equal to that undergone by one gram of radium; i.e. 3.7×10^{10} disintegrations sec.^{-1}

[8] Radioisotopes in Science and Industry, A Special Report of the Atomic Energy Commission. January, 1960, p. 2.

30.2 Scope: Except as provided in 30.6 to 30.8 the regulations in this part apply to all persons in the United States.

30.3 License requirements. No person subject to the regulations in this part shall manufacture, produce, transfer, receive, acquire, own, possess, use, import, or export byproduct material except as authorized in a specific or general license issued pursuant to the regulations in this part.

GENERAL LICENSES: APPLICATIONS FOR LICENSES

30.20 Types of licenses. (a) Licenses for byproduct material are of two types: general and specific. The general licenses provided in 30.21 are effective without the filing of applications with the Commission or the issuance of licensing document to particular persons. Specific licenses are issued to named persons upon applications filed pursuant to the regulations in this part.

30.21 General licenses. (a) A general license is hereby issued: (2) to transfer, receive, acquire, own, possess, use, and import the quantities of byproduct material listed in 30.72, provided that no person shall at any one time possess or use, pursuant to the general licensing provisions of this paragraph, more than a total of ten such scheduled quantities.

30.72 Schedule B. The following quantities of byproduct material are generally licenses pursuant to 30.21 (a) (2).

Byproduct Material	Column No. 1 Not as a sealed source (Microcuries)	Column No. 11 As a sealed source (Microcuries)
Antimony (Sb 124)	1	10
Arsenic 76 (As 76)	10	10
Arsenic 77 (As 77)	10	10
Barium 140-Lanthanum 140 (BaLa 140)	1	10
Beryllium (Be 7)	50	50
Cadmium 109-Silver 109 (CdAg 109)	10	10
Calcium 45 (Ca 45)	10	10
Carbon 14 (C 14)	50	50
Cesium 144-Praseodymium (CaPr 144)	1	10
Cesium-Barium 137 (CsBa 137)	1	10
Chlorine 36 (Cl 36)	1	10
Chromium 51 (Cr 51)	50	50
Cobalt 60 (Co 60)	1	10
Copper 64 (Cu 64)	50	50
Europium 154 (Eu 154)	1	10
Fluorine 18 (F 18)	50	50
Gallium 72 (Ga 72)	10	10
Germanium 71 (Ge 71)	50	50
Gold 198 (Au 198)	10	10
Gold 199 (Au 199)	10	10
Hydrogen 3 (Tritium) (H 3)	250	250
Indium 114 (In 114)	1	10
Iodine 131 (I 131)	10	10
Iridium 192 (Ir 192)	10	10
Iron 55 (Fe 55)	50	50
Lanthanum 140 (La 140)	10	10
Iron 59 (Fe 59)	1	10
Manganese 52 (Mn 52)	1	10
Manganese 56 (Mn 56)	50	50
Molybdenum (Mo 99)	10	10
Nickel 59 (Ni 59)	1	10
Nickel 63 (Ni 63)	1	10
Niobium 95 (Nb 95)	10	10
Palladium 109 (Pd 109)	10	10
Palladium 103-Rhodium 103 (PdRh 103)	50	50
Phosphorus 32 (P 32)	10	10
Polonium 210 (Po 210)	0.1	1
Potassium 42 (K 42)	10	10
Praseodymium 143 (Pr 143)	10	10
Promethium 147 (Pm 147)	10	10

Byproduct	Column No. I Not as a sealed source (Microcuries)	Column No. II As a sealed source (Microcuries)
Rhenium 186 (Re 186)	10	10
Rhodium 105 (Rh 105)	10	10
Rubidium 86 (Rb 86)	10	10
Ruthenium 106-Rhodium 106 (RuRh 106)	1	10
Samarium 153 (Sm 153)	10	10
Scandium 46 (Sc 46)	1	10
Silver 105 (Ag 105)	1	10
Silver 111 (Ag 111)	10	10
Sodium 22 (Na 22)	10	10
Sodium 24 (Na 24)	10	10
Strontium 89 (Sr 89)	1	10
Strontium 90-Yttrium 90 (Sr Y-90)	0.1	1
Sulfur 35 (S 35)	50	50
Tantalum 182 (Ta 182)	10	10
Technetium 96 (Tc 96)	1	10
Technetium 99 (Tc 99)	1	10
Tellurium 127 (Te 127)	10	10
Tellurium 129 (Te 129)	1	10
Thallium 204 (Tl 204)	50	50
Tin 113 (Sn 113)	10	10
Tungsten 185 (W 185)	10	10
Vanadium 48 (V 48)	1	10
Yttrium 90 (Y 90)	1	10
Yttrium 91 (Y 91)	1	10
Zinc 65 (Zn 65)	10	10

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[9]Excerpt from Title, Part 30, Federal Register, Vol. 21, Part 6, January 11, 1956.

Isotope	Usual Chemical Form	Half-Life	Beta Energy (Mev)	Gamma Energy (Mev)
Iodine 131.....	NaI.....	8.08 days.....	0.608 et...	0.364 et.
Phosphorus 32...	NaH_2PO_4....	14.3 days.....	1,701.....	None
Calcium 45.....	$CaCl_2$.....	163 days.....	0.254.....	None
Carbon 14.....	Na_2CO_3.....	5,562 yrs.....	0.155.....	None
Cesium 137.....	CsCl.....	30 yrs.....	0.51 et....	None
Barium 137.....	$BaCl_2$.....	2.6 min.	None.....	0.662
Chlorine 36.....	KCl.....	308,000 yrs....	0.714.....	None
Chromium 51.....	$CrCl_3$.....	27.8 days.....	None.....	0.32 et
Cobalt 60.....	$CoCl_2$.....	5.27 yrs.....	0.306.....	1.17, 1.33
Iron 59.....	$FeCl_3$.....	45.1 days.....	0.462 et...	0.191, 1098 1.289
Nickel 63.....	$NiCl_2$.....	85 yrs.....	0.067.....	None
Ruthenium 106...	$RuCl_3$.....	1.0 yrs.....	0.0392.....	None
Rhodium 106.....	$RhCl_3$.....	30 sec.....	3.53 et....	0.513, 2.41 et
Sodium 22.....	NaCl.....	2.6 yrs.....	0.58 B+....	0.511, 1.28
Strontium 89....	$SrCl_2$.....	53 days.....	1.463.....	None
Strontium 90....	$SrCl_2$.....	25 yrs.....	0.61.....	None
Yttrium 90.....	YCl_3.....	2.54 days.....	2.18.....	None
Sulfur 35.....	H_2SO_4.....	87.1 days.....	0.167.....	None
Thallium 204....	$TlNO_3$.....	4.0 yrs.....	0.765.....	None
Yttrium 90.....	YCl_3.....	2.54 days.....	2.18.....	None
Zinc 65.....	$ZnCl_2$.....	250 days.....	0.325 B+...	1.12 et

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[10] Excerpt from Federal Register, Vol. 21, Part 6, January 11, 1956.

The following companies will supply at present license-exempt quantities of radioisotopes:

1. Atomic Research Laboratory
   10717 Venice Boulevard
   Los Angeles, Calif. 90034

2. Abbot Laboratories, Division of
   Radioactive Pharmaceuticals
   P.O. Box 1008
   Oak Ridge, Tenn. 37831

3. Nuclear Chicago Corp.
   333 East Howard Avenue at
   Nuclear Drive
   DesPlaines, Ill. 60018

4. Isotopes Specialties Co., Inc.
   170 West Providencia Street
   Burbank, Calif. 91503

5. Nuclear Consultants, Inc.
   33-61 Crescent Street
   Long Island City, N. Y. 11105

6. Oak Ridge National Laboratory
   Radioisotope Sales Department
   P.O. Box P
   Oak Ridge, Tenn. 37831

7. Atomic Corporation of America
   7901 San Fernando Road
   Sun Valley, Calif. 91352

8. Beta Industries, Inc.
   P.O. Box 1407
   2275 Ted Dunham Avenue
   Baton Rouge, La. 70821

9. General Nuclear, Inc.
   9320 Tavenor
   Houston, Texas 77034

10. Chem-Trac
    Baird Atomic, Inc.
    33 University Road
    Cambridge, Mass. 02138

11. Iso-Serve, Inc.
    131 Portland Street
    Cambridge, Mass. 02139

12. New England Nuclear Corp.
    575 Albany Street
    Boston, Mass. 02111

13. Nuclear Consultants Corp.
    9842 Manchester Road
    St. Louis, Mo. 63119

14. Nuclear Science and
    Engineering Corp.
    P.O. Box 10901
    Pittsburgh, Pa. 15236

15. Nucleonic Corp. of America
    196 Degraw Street
    Brooklyn, N. Y. 11231

16. Schwarz Bio-Research, Inc.
    Mountainview Avenue
    Orangeburg, N. Y. 10962

17. Squibb, E. R. & Sons
    Georges Road
    New Brunswick, N. J. 08902

18. Tracerlab
    Technical Products Division
    1601 Trapelo Road
    Waitham, Mass. 02124

19. U. S. Nuclear Corp.
P.O. Box 208
Burbank, Calif. 91503

20. Valk Radiochemical Co.
8260 Elmwood Avenue
Skokie, Ill. 60076

Application-exempt quantities of Carbon-14 labeled compounds are available from:

1. Nuclear-Chicago Corp.
333 East Howard Avenue at
Nuclear Drive
DesPlaines, Ill. 60018

2. Fisher Scientific Co.
709 Forbes Street
Pittsburgh 19, Pa.

Catalogues are available from these companies. The isotopes are usually shipped via Air Mail Special Delivery in order to deliver those with short half-lives as quickly as possible. Shipments are usually received from the supplier the day following shipment, even though you may be separated by nearly three thousand miles. In order to insure the maximum activity at time of use, it would be wise to order in advance of a proposed experiment, and designate the day of delivery. This may be difficult if you purchase isotopes from Oak Ridge National Laboratory, as they only ship certain isotopes on certain days of the week.

III TEXTBOOKS AND REFERENCES

There is at present no text available which has been written for a course such as this. Rather, a number of references are needed to fill the requirements. The texts which must be used at present are necessarily of college reading level. However, this should pose no problem for the caliber of student enrolled in the course.

Glasstone's Sourcebook on Atomic Energy has been used successfully as a general text. A copy of this should be supplied to each student, and the assignments tailored to it. The choice of this text is due to several factors: It is quite complete in its coverage of the general aspects of the field; its presentation is quite readable and understandable on the Senior high school level; its low price of $4.40 puts it well within the normal high school budget.

A reference library should be installed in the classroom, and the students given free access to it for research and reference work.

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3rd Edition, 1967 New York D. Van Nostrand Co. $9.40

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Upton, New York, Information Division, Brookhaven National Laboratory — Free

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Washington 25, D. C.

B. Professional Level Film List

Washington, D. C., Technical Information Service — Free
U. S. Atomic Energy Commission
Washington 25, D. C.

VI. Free Booklets

A. The Atom In Our Hands

The Secretary
Union Carbide Corporation
270 Park Avenue
New York 17, N. Y.

B. Booklets available from Division of Technical Information, U.S.A.E.C.

1. Accelerators — William J. Kernan
2. Plutonium — William N. Miner
3. Atomic Fuel — John F. Hogerton

4.	Research Reactors	Martens & Jacobson
5.	Controlled Nuclear Fusion	Samuel Glasstone
6.	Neutron Activation Analysis	William R. Corliss
7.	Power from Radioisotopes	Robert L. Mead & William R. Corliss
8.	Synthetic Transuranium Elements	Earl K. Hyde
9.	Direct Conversion of Energy	William R. Corliss
10.	Food Preservation by Irradiation	Grace M. Urrows
11.	Microstructure of Matter	Clifford E. Swartz
12.	Careers in Atomic Energy	Loyce J. McIlhenny

IV EQUIPMENT

Equipment for the Nuclear Science course, due to its nature, is expensive. The following list represents the minimal requirements for the installation of a usable laboratory for student use. Additional items may be added at the discretion of the instructor, according to available funds.

MINIMAL EQUIPMENT LIST

Scaler with end window Geiger-Muller tubes and tube mounts (2)

Side-window Geiger-Muller tubes with mount and cable (2)

Lauritzen Electroscope (1)

Spinthariscope (1)

Wilson Continuous diffusion type cloud chamber (1)

X-ray film with film holders, developer, and acid fixer

Counting planchettes, plastic or metal (100)

Fiberglass isotope work tray (4)

Disposable plastic gloves (1 gross)

Assorted Micropipettes, 1 to 50 Lambda

Hypodermic syringes, Luer-lock, 10cc (5)

Propipetters (2) with 10cc pipettes

Saran wrap (1 roll)

Aluminum foil (1 roll)

Calibrated sources (1 ea. RaD & E and Co 60)

Stop watch (1)

Warning signs and warning tape (assorted)

Survey meter with side window tube (1)

Assorted laboratory glassware

Isotopes Required (License exempt amounts)

Carbon - 14	50	Microcuries
Cobalt - 60	1	"
Sodium - 22	10	"
Iron - 55	50	"
Zinc - 65	10	"
Lead - 210	0.1	"
Phosphorus - 32	10	"
Iodine - 131	10	"

Due to the short half lives of P^{32} and I^{131}, they must be purchased several times during the year as needed.

SOURCES OF EQUIPMENT

The following concerns supply equipment and may be contacted for their current catalogues:

1. Educational Materials & Equipment Co.
   Box 63
   Bronxville, N. Y. 10708

2. Atomic Acessories, Inc.
   811 West Merrick Road
   Valley Stream, N. Y. 11582

3. Nuclear Equipment Chemical Corp.
   145 Florida Street
   Farmingdale, N. Y. 11735

4. Nuclear-Chicago Corp.
   333 East Howard Avenue
   DesPlaines, Ill. 60018

5. Central Scientific Co.
   1700 Irving Park Road
   Chicago, Ill. 60613

6. Welch Scientific Co.
   7300 N. Linder Avenue
   Skokie, Ill. 60076

7. Atomic Corporation of America
   14275 Arminta Street
   Panorama City, Calif. 91402

8. The Nucleus
   P.O. Box R
   Oak Ridge, Tenn. 37830

An excellent source of specimen irradiation available to all teachers is the radiological laboratory of the local hospital. If the situation is explained in detail to the Radiologist in charge, it is possible that he will make his X-ray equipment available for this purpose. Excellent studies of the effect of radiation on seed germination and the production of mutations, to list just two, may be made with this equipment. This is also a possible source of isotopes and X-ray film.

V TYPES OF STUDENTS

This course should be intended primarily as an enrichment program for high ability students in the College Preparatory Course, especially those who plan to continue their formal education in one of the scientific disciplines. It is not recommended for students of low ability or achievement, since the pace should be rapid and the subject matter rigorous in comparison with the average high school course.

Emotional maturity is a must for the students who enroll in this program. They should be selected in order to eliminate those who are emotionally immature and therefore a hazard in the laboratory. An immature student might also arouse in the student body or the general public unfounded fears of the radiation hazard involved because of his statements outside the classroom.

The background of the student should include algebra I and II in order that he be able to correctly manipulate the equations and other mathematical computations necessary for comprehension of the subject matter involved. Some mathematics instruction, such as the use of natural logarithms and the slide rule may be necessary at the beginning of the course. A first year biology course should be required to insure sufficient babkground information to make some experiments in biological tracer techniques feasible.

This course should not be intended to replace physics or chemistry. One of these subjects should be taken simultaneously. Indeed, a course such as this should serve to bring about increased understanding of these subjects, rather than replace one of them.

The reading ability of the student should be of a superior nature, as the textbooks available at the present time are of college reading level. This, of course, may change in the future.

VI A COURSE OF STUDY FOR NUCLEAR SCIENCE

GENERAL OVERVIEW - The subject matter in this course cuts across the various scientific disciplines; consequently, it helps the college-bound student tie together the various science courses he has taken. Radioisotopes are used as tracers in physical, chemical, and biological experiments. The laboratory should be licensed by the Atomic Energy Commission and inspected by the Pennsylvania Department of Health. The course includes historical development of the atomic concept, atomic particles, electromagnetic radiations, the dualistic nature of radiant energy, some concepts of quantum theory, Compton scattering, the photoelectric effect, and radioactivity.

Persons of high academic ability who plan to continue their education in one of the scientific disciplines are encouraged to enroll. College Preparatory students in the eleventh and twelfth grades who have received credit for biology I and algebra I should be eligible. They should be simultaneously enrolled in either physics or chemistry and in the more advanced mathematics courses. This course is not designed to replace the basic curricular offerings, but is offered in addition to them.

UNIT I

INTRODUCTION: Atomic Energy

Suggested Time: 3 weeks

OVERVIEW - The early Greek Atomists held the view that all matter was composed of small indivisible particles or "atoma." This view was replaced by the theories of Aristotle which held sway for nearly 2,000 years until eliminated by the experimental and theoretical work of men such as Lavoisier, who gave us workable hypotheses from which our modern theories have evolved. A general comprehension of these early theories and how and why they have been replaced is perhaps the best way to understand the evolution of our present theories and to realize that these, far from being complete, are in constant revision in the light of new experimental knowledge.

OBJECTIVES

1. The class shall apply the historical evolution of the atomic theory as a prime example of science, using processes of induction and deduction from accrued data presented in the Nuclear Science Course to construct models that are subject to constant revision in the light of new experimental data.

   1.1 The student shall differentiate between inductive and deductive reasoning by identifying specific examples of each reasoning type from the material presented in the classroom.

   1.2 The student shall delineate graphically the Aristotelian view of matter and explain why it was no longer tenable following the work of Priestly and Lavoisier.

   1.3 The student shall explain the atomic concept as first proposed by Dalton. He shall indicate the modern modifications of the original theory, supplying the experimental reasons for these modifications.

   1.4 The student shall construct, in historical sequence, the Daltonian, Thompsonian, and Rutherfordian models of the atom. He shall list Bohr's modifications of the Rutherford atom and, finally, construct the probability cloud model.

   1.5 The student shall, in a test situation, correlate the symbol of each element with its accepted name from a list of all presently known elements. Eighty-five identifications from a total of one hundred and three shall be the lowest acceptable limit of performance.

   1.6 Given the periodic chart of the nuclides, the student shall identify the atomic weight, atomic number, electron shell configurations, number of neutrons, and common valence of atoms of elements chosen by the teacher.

      1.6.1 Given a chart of the nuclides, the student shall identify the isotopes, isobars, isotones and nuclear isomers of elements selected by the teacher.

1.6.1.1 From the above mentioned chart, the student shall identify the type and energy of the nuclear emissions of radioisotopes selected by the teacher. He shall also identify the daughter nuclide produced by the emission of that particle and construct a balanced nuclear equation for the reaction.

1.7 The student shall construct chemical formulas from a list of elements with their valences. He shall then calculate the molecular weights of these compounds. Utilizing the Avogadro number, he shall calculate the weight of a single molecule of a preselected compound.

CONTENT

I. The methods of science

A. Inductive and deductive reasoning
B. Microphysics vs. macrophysics

II. The atomic concept

A. Historical background

1. The early Greek Atomists
2. The Four Element Theory
3. Lavoisier and the death of the Aristotelian view
4. Dalton's Atomic Theory
5. The nuclear atom
6. Modern modifications of these theories

B. The chemical elements

1. Symbols
2. Atomic number
3. Atomic weight
4. Isotopes, isobars, isotones, nuclear isomers

C. Atoms and molecules

1. Compounds
2. The Molecular Concept
3. Molecular weights: The Mole
4. Molecular sizes
5. The Avogadro Number

SUGGESTED ACTIVITIES

Student Experiments

1. Scientific observation and description (Observations on a Candle: CHEM Study)
2. The Black Box: The methods of science (Chemical Bond Approach)
3. Determination of the operating voltage of the Geiger-Muller tube
4. The efficiency of a geiger counter
5. Construction of geiger counters
6. Statistics of counting
7. Determination of the Avogadro Number

Teacher Demonstrations -- lectures

In this unit the following are recommended:

1. Electron energy levels of the Bohr atom as indicated by emission spectra of substances energized with ultra-violet light.
2. The correct operating procedures for the radiological instruments used in the course
3. Shielding from nuclear radiations

Films

1. A is for Atom, 30 minutes, color
2. Living with Radiation, 45 minutes, color
3. Fundamentals of Radioactivity, 30 minutes, B&W

UNIT II

ATOMIC PARTICLES AND ELECTROMAGNETIC RADIATIONS

Suggested Time: 3 weeks

OVERVIEW - This unit shows the basic subatomic particles which constitute the atoms of matter and their relationships with each other.

OBJECTIVES

1. The student shall construct and demonstrate, in the manner requested by the teacher, theoretical models of atomic and subatomic structures from the material and data provided by the teacher, resource books, text, and experimental investigations in this unit.

   1.1 The student shall differentiate between static and dynamic electricity from demonstrations and experimentation in the classroom. He shall show this difference in the manner requested by the teacher.

      1.1.1 The student shall indicate comprehension of the units of measurement of electricity by utilizing these units to solve general problem types. (Units means volt, ampere, ohm, coulomb, and watt. Problem types means specific mathematical relationships between these units, and conversions from one unit to another.)

   1.2 The student shall construct graphically a model of the cathode ray tube. He shall state the properties of cathode rays (mass, charge, path in the tube), and shall state experimental evidence presented by classroom demonstrations to support his statements of properties.

   1.3 The student shall describe in a manner prescribed by the teacher the properties of the electron. (Properties means mass, charge, particle radius, and atomic position.)

   1.4 The student shall describe from the material presented in the course the production, absorption, wavelengths, and general nature of X-rays.

1.5 The student shall, in a test situation, name the properties of the neutron, proton, alpha particle, beta particle, deuteron, neutrino, pi, mu, and K mesons, triton, and cosmic rays. (Please refer to 2.3 for the definition of properties.) The correct identification of nine from a list of eleven shall be the lowest acceptable standard of performance.

1.5.1 For each of the above particles, the student shall identify by graphic means its matching antiparticle. He shall, by utilizing the Einstein mass-energy equation, calculate mathematically the energy produced by the mutual annihilation process--the collision of each particle with its antiparticle.

1.5.2 Given the mass in grams of one atomic mass unit, the student shall calculate mathematically its energy equivalence by utilizing the mass-energy relationship. He shall then convert this into Mev.

1.6 The student shall construct graphically nuclear equations for the bombardment of nuclei by particles and for the transmutations occurring from radioactive emanations.

CONTENT

I. The fundamental nature of electricity

- A. Static and dynamic electricity
- B. Units of measurement
- C. Current flow
- D. Cathode rays and the Edison Effect
- E. Vacuum tubes

II. The fundamental particles: Leptons, Hyperons, and Baryons

- A. Electron
- B. Proton
- C. Neutron
- D. Positron
- E. Antiproton
- F. The Mesons
- G. Alpha particles
- H. Neutrinos
- I. X and Gamma radiation
- J. Cosmic rays and strange particles
- K. Antiparticles

III. Matter - antimatter interactions

A. Annihilation radiation
B. Mass-energy relationship
C. Energy equivalent of one atomic mass unit
D. Mass - energy interconversions

SUGGESTED ACTIVITIES

Student Experiments

1. Calculation of dead time or resolving time of a G-M tube
2. Particle tracks in the Wilson Cloud Chamber
3. Cosmic rays
4. Indestructability of radioactivity
5. Magnetic deflection of beta particles

Teacher Demonstrations

1. Determination of the e/m of the electron
2. The Van de Graaf Electrostatic Generator
3. Static electricity; attraction and repulsion
4. The Cathode Ray Tube
5. Magnetic deflection of cathode rays

Film

1. The Radioisotope: Methodology, 45 minutes, B&W

UNIT III

THE DUALISTIC NATURE OF RADIANT ENERGY

Suggested Time: 5 weeks

OVERVIEW - This unit introduces the student to the Newtonian or corpuscular theory concerning the nature of radiant energy, and to the electromagnetic theory of these radiations. The dilemma of supporting proof for both theories is alleviated by the dualistic explanation. A study of basic Quantum Mechanics leads the student to the relativistic concepts of Lorentz and Einstein, and the general and special theories of relativity are explored.

OBJECTIVES

1. The student shall apply (by explaining specific cases supplied by the teacher) the dualistic explanation of radiant energy to resolve the apparent contradictions shown by the Newtonian or corpuscular and the electromagnetic theories of light.

   1.1 The student shall construct a model of the electromagnetic spectrum from the materials presented by the teacher, the text, laboratory investigations, and audio-visual materials. He shall differentiate between the accepted areas of the spectrum from radio waves to cosmic rays.

      1.1.1 The student shall show the mathematical relationships between the energy, frequency, and wavelength of an electromagnetic wave by solving teacher-constructed problems. Eight correct solutions from a total of ten presented shall be the minimum acceptable level of performance.

      1.1.2 Given the index of refraction, the student shall calculate the velocity of light traveling through various transparent meida.

   1.2 The student shall describe the model of an ideal "black body" from material presented in the class.

   1.3 From material presented in the class, the student shall explain the current theories of light emission by atoms. He shall explain the production of emission and absorption spectra, utilizing the material described above.

1.4 The student shall theorize as the teacher requests to explain Laue patterns produced by crystals (acting as diffraction gratings) as acceptable indications of the wave nature of electromagnetic radiations and of subatomic particles approaching the velocity of light.

1.5 Utilizing the Heisenberg uncertainty principle, the student shall correctly determine the uncertainty in position or velocity of electrons in specific problematical cases presented by the teacher.

2. The student shall utilize mathematically the relativistic concepts of Lorentz and Einstein to calculate mass increase, time dilation, length decrease, and energy transformations occurring to subatomic particles approaching the velocity of light.

2.1 Utilizing the Lorentz relativistic equations, as presented by the class, reference works, and the teacher, the student shall show by means of mathematical calculations the changes in mass, length, time, momentum, and energy occurring to any body approaching the velocity of light.

2.1.1 From these equations the student shall explain orally and graphically why the velocity of light is postulated to be the ultimate speed in the universe.

2.2 Given the Einstein mass-energy relationship and Planck's equations, the student shall explain, in a manner chosen by the teacher, the unified theory of the relationship of mass and energy.

2.3 The student, utilizing the material presented in this unit, shall show the theoretical reasons why particles are accelerated to extremely high velocities for nuclear bombardment.

2.4 Using the Lorentz equations as background material, the student shall explain, in a test situation, the Special Theory of Relativity, as required to do so by the teacher.

CONTENT

I. Waves

A. The Quantum Theory
B. Planck's Constant

C. Diffraction of waves
D. Heisenberg: The Principle of Uncertainity
E. The significance of wave properties

II. Particulate characteristics of radiations

A. The photon
B. Compton scattering
C. The photoelectric effect

III. Wave - particle duality

IV. Relativistic relationships

A. The velocity of light
B. The Lorentz Equations
C. The general and special theories of relativity
D. The Conservation of Mass-energy

SUGGESTED ACTIVITIES

Student Experiments

1. Waves on a coil spring
2. Experiments with the ripple tank
3. Wave diffraction

Teacher Demonstrations

1. Models of changes in the mass and length of an arrow as it approaches the velocity of light (graded lengths.) Calculate length and mass changes utilizing the Lorentz Transformations.

Lecture - Discussions

1. Newtonian and wave theories of light
2. The Quantum Theory
3. The deBroglie Equations
4. Compton scattering
5. Conflicts between Quantum physics and Newtonian physics
6. Defense of Newtonian physics

UNIT IV

THE STRUCTURE OF THE ATOM

Suggested Time: 5 weeks

OVERVIEW - Dalton considered the atom to be an infinitely small, indivisible, solid particle. Later theories pictured it to consist of opposing charges located upon the surface of a solid sphere. With Rutherford's theory of the nuclear atom, experimental investigations led to the modern concepts of the nature of the atom and to the understanding of subatomic structures and forces.

OBJECTIVES

1. The student shall apply nuclear theory as presented by the resource materials to construct, as required by the teacher, currently acceptable models of the atomic nucleus. He shall indicate lapses in our present knowledge that will probably lead to alterations of these models.

    1.1 The student shall repeat Objective 1.4, (Unit I), including the refinements presented in this unit.

        1.1.1 The student shall construct nuclear models of atoms selected by the teacher. He shall include in this model the nuclear radius, the neutron-proton ratio, the binding energy, the packing fraction, and the nuclear volume.

    1.2 The student shall define orally and graphically the concepts of isotopes, isobars, isomers, and isotones by indicating the mass numbers and atomic numbers of the respective nuclides.

    1.3 The student shall utilize the concept of binding energy produced by the mass defect to explain, theoretically, differences which occur in nuclear stability.

    1.4 Utilizing the concept of nuclear isomerism, the student shall explain why particles with varying energies are emitted from the nucleus. He shall use these concepts to explain gamma emission.

1.5 Given the nuclear spin quantum numbers, the student shall demonstrate in a mathematical manner that nuclear spin is the resultant of the individual spins of the nucleons.

1.6 The student shall construct, in the accepted manner, energy level diagrams for nuclear reactions.

1.7 The student shall construct an energy level model of the nucleus from the information presented by the text, the teacher, and resource materials concerning isomeric transition, periodicity in packing fractions and binding energies, the "magic number nuclei," evidence of neutron-proton pairing, and gamma emission.

1.8 Given a nuclear reaction and the masses of all particles involved, the student shall calculate the energy of that reaction.

CONTENT

I. Early theories

A. Dalton
B. Thomson

II. Rutherford and the nuclear atom

A. The nucleus

1. Nuclear particles
2. Nuclear binding energy
3. Nuclear mass and size
4. Changes within the nucleus
   a. A and Z numbers
   b. Nuclear emissions
   c. Transmutations
   d. Isotopes, isobars, isotones, nuclear isomers
5. Nuclear charge
   a. Nuclear energy levels
   b. Gamma radiation

B. Orbital electrons

1. Charge and mass
2. Electron orbitals
3. X-ray spectra

III. The probability concept of the atom

SUGGESTED ACTIVITIES

Student Experiments

1. Beta particle shielding
2. Gamma ray shielding
3. Determination of half-thicknesses of absorbers
4. Safety and decontamination procedures

Films

1. Nuclear Explosives, 40 minutes, color
2. Industrial Applications of Nuclear Explosives, 30 minutes, color

UNIT V

RADIOACTIVE ELEMENTS

Suggested Time: 4 weeks

OVERVIEW - This unit develops the basic principles governing the emission and absorption of nuclear radiations and the effects of these emissions and absorptions upon matter through which they pass.

OBJECTIVES

1. The student shall demonstrate the principles of radioactive decay by explaining (by means of graphic and verbal tests) the mechanics of alpha, beta, positron, and gamma emission, the random nature of radionuclide disintegration, the formation of decay chains, and the concept of half-life.

   1.1 The student shall relate, as required by the teacher, the historical background of the discovery of radioactivity by Becquerel and Curie.

1.2 The student shall identify the naturally occurring types of emitted particles as to mass, charge, and energy ranges.

1.3 The student shall describe (by means of nuclear equations) one of the four natural radionuclide decay chains, showing all parent and daughter nuclides.

1.4 The student shall construct, on semilogarithmic graph paper, a graph of counts-per-minute of a phosphorus 32 sample, taken daily over a several-day period, plotted against time in days. From this graph he shall calculate the half-life of the element and its decay constant.

1.4.1 Using two counts from the above data, the student shall determine algebraically the decay constant and half-life of phosphorus 32.

1.4.1.1 Given any two counts from the same sample separated by a suitable time interval, the student shall calculate the decay constant and half-life of the sample.

1.4.1.1.1 The student shall repeat Objectives 1.4, 1.4.1, and 1.4.1.1, utilizing iodine 131.

1.5 From the material presented in class, the student shall construct a graph and utilize it to explain radioactive equilibrium.

1.6 Given any equation representing radioactive decay, the student shall construct an energy level decay scheme for that particular reaction. (See Objective 5.6)

1.7 Given the half-life of any radionuclide, the student shall calculate the mean life for any atom of that radionuclide.

1.8 The student shall explain, in the manner requested by the teacher, the separation of radioactive decay products, the use of carriers for radioisotopes, and the recoil method of radionuclide separation.

1.9 The student shall supply examples of the utilization of radioisotopes as "tracers" in biological and chemical systems.

CONTENT

I. The nature of radioactive emanations

   A. Alpha particles
   B. Beta particles and positrons
   C. Electromagnetic radiations

II. Naturally radioactive elements

III. Artificially induced radioactivity

IV. Induced and spontaneous transmutations

V. Radioisotopes - radionuclide production

VI. Radioactive decay

   A. Decay as a random process
   B. Natural and artificial disintegration series
   C. Half life
   D. Daughter nuclides

SUGGESTED ACTIVITIES

Student Experiments

1. Determination of half-life I^{131}
2. Determination of half-life P^{32}
3. The construction of half-life curves and calculation of decay constants.
4. Separation of radioactive compounds by paper chromatography and chromatogram scanning
5. Background radiation: air sampling

Films

1. Radioisotopes: Their Applications to Humans, 40 minutes, B&W
2. Radioisotopes in Industry, 40 minutes, color
3. Ionizing Radiations in Humans, 40 minutes, color

UNIT VI

MEASUREMENT OF NUCLEAR RADIATIONS

Suggested Time: 2 weeks

OVERVIEW - This unit familiarizes the student with the various devices in present use to detect nuclear radiations.

OBJECTIVES

1. The student shall show by demonstration, oral explanation, and graphic means the utilization of various devices designed to detect and record the presence of ionizing radiations.

    1.1 The student shall explain, in the manner required, that all radiations lose their energy by causing ionizations within the material through which they pass.

        1.1.1 Given the fact that an ionizing event requires an average energy of thirty-four electron volts, the student shall calculate the total ionization if any radiation for which he is given the energy.

        1.1.2 The student shall relate the specific ionization (number of ion-pairs per unit of track length) to the charge and velocity of the radioactive particle. He shall contrast this with the total ionization of the particle.

            1.1.2.1 From the above material, the student shall name in order the most damaging radiations to a biological system from internally and externally deposited radionuclides.

    1.2 From the classroom material concerning the loss of energy of a radioactive particle by ionization, the student shall explain, in a test situation, the absorption of beta particles producing bremsstrahlung ("braking radiation").

    1.3 The student shall explain in a written and oral manner the theory and operation of the ionization chamber. He shall differentiate between integrating and nonintegrating instruments and discuss the uses of scalers.

1.4 The student shall indicate comprehension of the utilization of the Lauritzen electroscope by using this instrument to compare the radioactivity of two different samples and to determine the half-life of a short-lived radionuclide.

1.4.1 Using the classroom model of the electroscope, the student shall name its component parts and their functions in an oral examination.

1.5 Presented with a Geiger-Muller tube having the end window removed, the student shall identify the parts by naming them orally. He shall explain in a written test the theory of operation of the tube, including the type of gas within the tube, the concept of the Townsend avalanche, the need for and the mechanics of quenching, the gas amplification factor, and the resolving time.

1.6 The student shall reconstruct graphically the idealized graph of counts per minute versus applied voltage of a Geiger-Muller tube. Areas of the graph that he will identify are the starting voltage, threshold of the plateau, the Geiger-Muller plateau, and the area of continuous discharge. He will then select the optimal operating voltage for the tube.

1.7 From the material presented by the text, the teacher, and resource materials, the student shall, in a test situation, present the theory of radiation detectors which operate on the principle of phosphor scintillation produced by incident radiations. (Radiation detectors means: the spinthariscope and scintillation spectrometer.)

1.7.1 The student shall utilize the spinthariscope to compare the radioactivity of two different samples. He shall indicate an activity ratio in a written laboratory report.

1.7.2 The student shall construct diagrammatically a model of the photomultiplier tube and explain its operation by indicating how flashes of light from a crystal are converted into electrical impulses in the tube.

1.8 The student shall indicate a working knowledge of the Wilson cloud chamber by setting up, operating, and explaining the tracks produced in the chamber.

CONTENT

I. Ionization counters (chambers)

II. Proportional counters

III. Geiger-Muller Counters

IV. Scintillation counters

A. Spinthariscope
B. Scintillation spectrometers

V. Cloud chambers and bubble chambers

VI. Photographic emulsions

SUGGESTED ACTIVITIES

Student Experiments

1. The Spinthariscope
2. The Lauritzen Electroscope
3. Autoradiography

Teacher Demonstrations and Lectures

1. Theory of the Proportional Counter
2. Autoradiographic techniques

UNIT VII

PARTICLE ACCELERATORS

Suggested Time: 2 weeks

OVERVIEW - This unit is designed to acquaint the student with the various types of accelerators, their construction, and the specific particles for which they can be employed.

OBJECTIVES

1. The student shall explain orally and mathematically the operation of accelerating devices designed to penetrate the nuclear coulombic barrier to positively charged ions, and he shall explain, in the manner required by the teacher, the nuclear mechanisms by which transmutations occur.

   1.1 The student shall present, in writing, theoretical explanations of the mechanisms of teacher-selected examples of artificially induced nuclear transmutations, including the primary nuclide, the impinging particle, the products, and the energy requirements of the reaction. He shall include all mass and charge numbers in the equations.

   1.2 The student shall construct models (as required by the teacher) of the Cockroft-Walton voltage multiplier and the Van de Graaff electrostatic generator. He shall explain the mechanics of the voltage buildup, discharge and ion acceleration.

   1.3 Given a schematic diagram of the drift-tube type of linear accelerator, the student shall identify and indicate the functional mechanisms of the graduated length drift tubes, the R-F oscillator, and the ion source.

   1.4 Given a schematic diagram of the cyclotron, the student shall identify and indicate the function of the dees, electromagnet, and R-F oscillator. He shall identify the relative positions of the electric and magnetic fields and explain theoretically the function of the eddy currents which carry the ions, and the method of acceleration of these ions.

      1.4.1 The student shall describe mathematically the motion of ions within the cyclotron. He shall predict by calculations the radius, angular momentum, and energy of a specific ion under conditions selected by the teacher.

   1.5 The student shall describe graphically and mathematically the betatron when given a schematic diagram of that device. He shall identify the components and their functions.

CONTENT

I. Voltage multipliers

II. Van de Graaff Electrostatic Generators

III. Cyclotron

IV. Betatron

V. Linear accelerators

SUGGESTED ACTIVITIES

Student Experiments

1. The Van de Graaff generator
2. The Discharge tube
3. Particle collisions. (Use billiard balls or ball bearings)

Teacher Demonstration

1. The Van de Graaff Electrostatic Generator
2. Defection of electrons in a cathode ray tube
3. Eddy currents in the model cyclotron
4. Model mass spectrometers
5. The relationship of particle mass to its deflection in a magnetic field. (Use steel ball bearings on inclined plane, and a large permanent magnet.)

Films

1. <u>High Energy Particle Accelerators</u>, 40 minutes, color

UNIT VIII

NUCLEAR FISSION

Suggested Time: 3 weeks

OVERVIEW - This unit explains in depth the mechanics of nuclear fission and the requirements which must be met to achieve a sustained chain reaction.

OBJECTIVES

1. The student shall apply nuclear theory as presented by the teacher, the text, and resource materials to construct models of the mechanics of fission and the sustained chain reaction. He shall demonstrate, verbally and graphically, utilizing drawings and models, the construction of nuclear reactors designed to control the fission process; and he shall illustrate, on a teacher-prepared test, the logical reasons for utilization of either graphite or water moderated reactors.

   1.1 The student shall write the generalized nuclear equation for the fission process. He shall include the mass and charge numbers and indicate the average number of neutrons produced and the average energy in megavolts per fission.

   1.2 Given a specific nuclear fission equation and the masses of all reactants and products, the student shall calculate mathematically the mass loss and the energy release.

   1.3 Given a semilogarithmic chart of the nuclei formed in fission, the student shall, in the manner required by the teacher, identify the mass number of the nuclides most frequently formed. From this chart he shall show the graphic methods of computing the mass distribution of products.

   1.4 The student shall, in a test situation, differentiate between prompt and delayed neutrons resulting from fission.

   1.5 Utilizing the liquid drop nuclear model as presented in the class, the student shall graphically illustrate the concept that fission is caused by the captured neutron supplying sufficient energy to deform the nucleus to the state where electrostatic repulsion overcomes the binding force.

1.6 The student shall, from the materials supplied by the teacher, the text and resource materials, illustrate graphically the concept of the chain reaction occurring when sufficient nuclei are present to assure probability of the capture of polyergic neutrons produced by fission (critical mass).

1.7 From the materials presented in the class, the student shall define, in a test situation, the following items: fast neutron fission, slow neutron fission, fissile isotopes, neutron moderators, critical mass, critical density, and multiplication factor. The lowest limit of acceptable performance is seventy percent correct identification.

1.8 Given a schematic diagram of a typical swimming-pool-type nuclear reactor, the student shall identify and note the function of the fuel charge, pool, control rods, biological shield, neutron reflector, irradiation blocks, and heat exchanger.

1.9 The student shall list the similarities and differences between the nuclear reactor and the fission bomb. A list of ten similarities and/or differences shall be the lowest acceptable limit of performance.

1.9.1 The student shall construct models of and explain the differences between the critical mass or gun barrel bomb and the critical density or implosion bomb.

1.9.2 The student shall, on a teacher-prepared test, identify the fast neutron fissibility of the bomb, its energy release in kiloton equivalents, the temperature of the fireball, and the blast characteristics. He shall illustrate fallout patterns dependent upon the blast altitude and indicate the production of radioactive debris by the formation of fission products by the fireball.

CONTENT

I. The concept of fission

A. Fissile isotopes
B. Energy release
C. The mechanics of fission

1. The chain reaction

2. Critical mass and density
3. Fission products
4. The liquid drop nucleus

II. The fission bomb

A. History
B. Types

1. Critical mass (gun barrel) bomb
2. Implosion (critical density) bomb

III. Controlled chain reactions

A. The nuclear reactor

1. Fissile isotopes as fuel
2. Neutron source to sustain criticality
3. Moderators and control rods
4. Coolants
5. Biological shielding

B. Reactor types

1. Graphite moderated
   a. boiling water
   b. pressurized water
2. Swimming pool reactors

C. Reactor uses

1. Power
2. Isotope production
3. As a high level source of neutrons and gamma rays

SUGGESTED ACTIVITIES

Student Experiments

This unit, as the last, does not lend itself to correlated student experiments. However, the use of well-selected films is designed to fill this void. The following experiments are designed to further familiarize the students with radiological methodology.

1. Electroscopes
2. Identification of radiations emitted by a source
3. Shielding of alpha particles

Teacher Demonstrations

1. The Chain Reaction (Demonstrated with mousetraps attached with threads.)

Films

1. Research Reactors, U.S.A. 45 minutes, color
2. EBR-I Core Assembly After Meltdown, 30 minutes, B&W
3. Reactors Fuel Processing, 30 minutes, color

Field Trip

A trip to a nuclear reactor would reinforce this unit by allowing the student to see on a first hand basis the practical applications of the material presented in the unit. A trip might be arranged to one of the following Pennsylvania reactor facilities.

1. Shippingport Nuclear Power Plant
   Shippingport, Pa.

2. Peach Bottom Nuclear Power Plant
   York County, Pa.

3. The Pennsylvania State University Nuclear Reactor Facility
   University Park, Pa.

UNIT IX

NUCLEAR FUSION

Suggested Time: 2 weeks

OVERVIEW - This unit is designed to acquaint the student with the theory and mechanics of nuclear fusion, and the energy release which accompanies it.

OBJECTIVES

1. The student shall demonstrate theoretically by problem-solving the fusion of light nuclei into heavier nuclei with a resulting mass loss producing energy. He shall apply the concepts of the pinch effect to construct a model of the "magnetic bottle" as a device to contain this thermonuclear process.

   1.1 The student shall construct nuclear equations to illustrate the mechanics of fusion and calculate from these equations the energy release per fusion event. He shall also indicate, in the manner requested, the conditions required for the initiation of fusion.

   1.2 The student shall write the carbon cycle equations and the proton-proton equations of stellar fusion processes.

   1.3 The student shall discuss, by means of diagrams and written explanation, the concept of the "magnetic bottle" to form a vessel for fusion reactions.

CONTENT

I. Fusion of light nuclei

   A. Carbon cycle
   B. Proton-proton chain

II. The thermonuclear reactions

   A. Deuterium and tritium reactions
   B. Energy release in fusion
   C. Requirements for fusion reactions

III. Attempts to harness fusion - magnetic bottle

IV. Production of energy in the Cosmos

Films

1. Research in Controlled Fusion, 45 minutes, color
2. The Magnetic Bottle, 45 minutes, color
3. Operation Crossroads, 45 minutes, color

UNIT X

RADIATION HEALTH PHYSICS

Suggested Time: 3 weeks

OVERVIEW - This unit is designed to give the student a basic understanding of the hazards of radiation dangers, the units of radiation dosage, and the decontamination procedures used in case of accidental contamination.

OBJECTIVES

1. The student shall apply data concerning the biological effects of ionizing radiations as presented by the teacher, the text, and resource materials to explain the processes whereby cells are damaged or destroyed by these radiations. He shall (verbally and by the construction of devices) demonstrate the effects of shielding and radiological decontamination procedures designed to minimize this damage.

    1.1 Given a list of protoplasmic changes in living cells, the student shall identify those effects which are directly attributable to radiation damage.

    1.2 The student shall list in chronological order the general symptoms of persons who have received an acute dosage of radiation. He shall identify a whole-body does of 450 REM as LD 50-30.

    1.3 The student shall list on a test the possible results of chronic subacute radiation exposure. In this list, he shall be required to note the cytological (genetic and somatic) changes which occur.

    1.4 The student shall, when presented with a prepared list of tissues, note whether they are radioresistant, of intermediate radiosensitivity, or radiosensitive.

    1.5 By utilizing the material presented in the class, the student shall illustrate, in the manner required by the teacher, the mechanisms of preferential uptake of radionuclides following ingestion. He shall list at least three isotopes involved and identify the body organs which tend to accumulate the isotopes which he listed.

1.6 Given the physical and biological half-lives of specific radionuclides, the student shall determine mathematically their effective half-lives when utilized as "tracers" in biological systems.

1.7 In a test situation, the student shall identify the following units of exposure to radiation: Roentgen, RAD, REM, REP, and RBE. (Identify means: a denotation of the numerical relation to the basic unit, the roentgen. The roentgen must be identified as ionization in ergs per gram of dry air.)

1.8 The student shall state on a test the maximum permissible dosages to ionizing radiation set by governmental regulatory agencies.

1.9 The student shall construct diagrams accompanied by a written explanation to show the theories of operation of the devices commonly utilized to record the radiation exposure of individual personnel (specifically, the film badge and the pocket dosimeter.)

1.10 From the materials presented by the teacher, the text, and resource material, the student shall describe the mechanisms of genetic damage due to radiation and the possible effects of this genetic damage.

CONTENT

I. Effects of radiation upon biological organisms

- A. Physical effects
- B. Mutagenic effects
- C. Comparison of acute and chronic exposures

II. Quantitative concepts

- A. Biological half-life
- B. Effective half-life
- C. Quantitative exposure units
  1. Roentgen
  2. RAD (Radiation Absorbed Dose)
  3. REP (Roentgen Equivalent Physical)
  4. REM (Roentgen Equivalent Man)
  5. RBE (Relative Biological Effectiveness)
  6. MPD (Maximum Permissible Dose)
  7. LD 50-30 (Lethal Dose for 50% of the population within 30 days)

8. MPC (Maximum Permissible Concentration)

SUGGESTED ACTIVITIES

Student Experiments

1. Safe radioisotope handling (unsealed sources)
2. Area monitoring
3. Radiation safety procedures (including decontamination)

Teacher Demonstration

1. Shielding methods

UNIT XI

RADIOISOTOPE APPLICATIONS

Suggested Time: 1½ weeks

OVERVIEW - No course in nuclear science is complete unless the student is made aware of the almost limitless applications of radioisotopes being utilized by industry, medicine, and the other disciplines as a research tool.

OBJECTIVES

1. The student shall use radioactive materials as investigative tools by devising and completing an original laboratory investigation in either the physical or biological sciences, utilizing tracing techniques in the solution of his problem. In conjunction with this investigation, he shall prepare and submit for grading a formal research report.

   1.1 The student shall, on a teacher-prepared test, cite at least two investigations from those presented in class to illustrate the utilization of radionuclides to "tag" molecules in biological and physical investigations.

   1.2 The student shall list, on a test, the major sources of available radioisotopes. The lowest acceptable limit of performance shall be three sources.

1.3 Given the physical and biological half-lives of specific radionuclides, the student shall calculate mathematically the effective half-life and the minimum detectable weight of that radionuclide for radiobiological investigations.

1.4 From the materials presented in the class, the student shall list at least three isotopes which are preferentially absorbed and identify the organs which accumulate that isotope. (Please refer to Objective 1.5 in Unit I.)

1.5 Given the pertinent data, the student shall, utilizing the method of dilution analysis, calculate the volume of blood in a hypothetical accident victim and indicate whether or not that patient requires a transfusion.

CONTENT

I. Uses of radioisotopes

II. Stable and radioactive isotopes

III. Isotope production

IV. Labelled compounds

V. Radioautography

VI. Biological applications

VII. Applications in chemistry and physics

SUGGESTED ACTIVITIES

Student Experiments

1. Absorption of P^{32} by plants
2. Absorption of I^{131} by plants
3. Determination of solubility

In conjunction with this unit, each student should be required to undertake an investigation of a laboratory problem involving the use of a radioisotopic "tracer". This may be an individual project or one involving a group of not more than three students. These are undertaken under the direct supervision of the instructor to insure strict adherence to radiological safety procedures. A formal research report should be submitted in conjunction with this work. A list of possible student investigations is included in the guide sheets.

VII LABORATORY OBJECTIVES
FOR
NUCLEAR SCIENCE

1. The student shall indicate to the teacher, orally and manually, operational skills pertinent to correct utilization of the scaler assigned to him.

   1.1 The student shall indicate on his scaler the operational controls. (Operational controls means the off-on switch, high voltage switch, meter zero adjustment knob, high voltage rheostat, voltage indicator, count reset button, calibration switch, and timer reset button.)

   1.2 The student shall, in correct sequence, undertake the operations to prepare the scaler for sample counting.

   1.3 The student shall, after using the calibration switch for a time interval selected by the teacher, convert the resultant count from binary to the base ten number system.

   1.4 Given a radioactive sample, the student shall determine background activity, count the sample, and convert this count to a true count-per-minute value for that sample, including the standard deviation.

2. Given a new Geiger-Muller tube for the scaler, the student shall count a sample in a regular progression of voltages. He shall graph this information as counts per minute versus voltage.

   2.1 On the graph described in Objective 2, the student shall indicate the threshold voltage, Geiger-Muller plateau, the area of continuous discharge, and the operating voltage.

3. Given a calibrated radioactive source, the student shall determine its activity on his scaler. From these data, he shall calculate the efficiency of his scaler. He shall repeat this procedure for each shelf of his sample holder.

4. The student shall make at least 40 one-minute counts of the sample under identical conditions. From these data, he shall determine the mean, medium, and most probable count of that sample.

   4.1 From the above data, the student shall calculate the standard deviation of the count.

5. Given a set of radionuclides of high activity, the student shall determine the "dead time" (resolving time) of the scaler.

   5.1 Given an extremely radioactive sample, the student shall obtain a count for that sample. He shall then, utilizing the scaler dead time, determine mathematically a correct count.

6. By counting a sample at successive intervals of one centimeter, the student shall show, graphically, that the number of counts per minute varies inversely with the square of the distance.

7. Utilizing a beta-emitting radioisotope and the calibrated absorbers, the student shall calculate graphically the half-thickness of the absorber material from data which he has obtained.

   7.1 Using lead absorbers with the same radioactive source, the student shall produce and detect bremsstrahlung radiation.

8. Using a gamma-emitting radioisotope and the lead absorbers, the student shall, from the data collected, determine the mass absorption coefficient and the absorber half-thickness.

   8.1 From the data obtained under Objectives 7 and 8, the student shall, on a written laboratory report, identify at least two problems pertaining to the construction of biological shields for radiation protection.

9. The student shall record the effects of backscattering of beta particles from data procured by counting the activity of a calibrated source over varying absorber thicknesses.

10. Using data obtained from determination of counts per minute of a stationary sample and cylinders of pure metallic elements of varying atomic weights, the student shall construct a graph of counts per minute versus atomic weight. He will then be given a cylinder of unknown material. Utilizing the method described above, he shall determine the atomic weight and the identity of the unknown element.

11. Utilizing a collimated stream of beta particles passing between the poles of an electromagnet, the student shall locate the stream of particles with an end window tube and measure the amount of deflection. From these data he shall determine the polarity of the electromagnet.

12. Utilizing the methods and results of Objectives 7 and 8, the student shall identify the radiations being emitted from an unknown radioactive source.

13. From daily counts of prepared samples of iodine 131 and phosphorus 32, the student shall calculate, graphically and mathematically, the half-life and decay constant (lambda value) of each radioisotope.

14. The student shall, in a laboratory situation, separate "tagged" molecules of differing molecular weights by ascending paper chromatography and identify the rate of flow by means of auto-radiographs which he has prepared.

VIII GUIDE SHEETS TO ACCOMPANY

SYLLABUS FOR

NUCLEAR SCIENCE

The following guide sheets were prepared to follow Glasstone's Sourcebook on Atomic Energy.

Unit 1

The Atomic Theory

1. Trace historically the broad concept of the atomic structure of matter.
2. Which men revived this concept during the Renaissance?
3. Who is given credit for the modern atomic theory?
4. How did he change this concept into a concrete theory?
5. How correct were Dalton's atomic weights?
6. What was the four-element theory of matter?
7. Describe Aristotle's concept of matter.
8. How did the work of Priestly and Lavoisier cause the four-element theory to be abandoned?
9. State Lavoisier's concept of an element.
10. How many elements did Lavoisier list? How correct was he?
11. How many elements are known today?
12. What is a compound?
13. Define the term transmutation.
14. Discuss the present concept of an element.
15. Discuss in detail the modern concept of an atom.
16. Describe and illustrate several of Dalton's symbols for the elements.
17. How did Berzelius improve the symbols for elements?
18. How is the formula of a compound written?

We will now leave this study guide to consider the Chemical Symbols, and their combinations into formulas. You will be expected to know the symbols of the elements, and will be tested on them.

19. Who is given credit for formulating the periodic law?
20. Wherein did the periodic chart have its most striking successes?
21. What elements were discovered to fill in gaps in the periodic chart which exactly followed Mendeleev's predictions?
22. Describe what we mean by periods and groups in the periodic table.
23. Why do we have group 0 in the chart?
24. Why are the Lanthanides (rare earths) grouped together in Group III A, Period 6?
25. Name the members of the Lanthanide Series.
26. Discuss the Actinide Series and name its members.
27. What is the size of a molecule (Kelvin's measurement)?
28. What is Avogadro's Law?
29. What is a mole (gram molecular weight)?
30. What is STP (Standard Temperature and Pressure)?
31. What is a Molar Volume (The volume of one mole of an inclosed gas at STP)?
32. What weight of H_2 would make a molar volume? Cl_2? Kr?
33. What is the Avogadro number?
34. How, by using the Avogadro number, would you find the weight of a single molecule in grams?
35. Describe Brownian Movement and its cause.
36. Compare the number of atoms per volume in liquids, solids, and gases.
37. What is the weight in grams of a single H atom? Would this be the approximate weight of a proton?
38. What is the weight in grams of a single uranium atom?
39. What is the approximate diameter of an atom?
40. What is an Angstrom Unit?

IMPORTANT ELEMENTS

1.	Actinium	Ac	8.	Bismuth	Bi
2.	Aluminum	Al	9.	Boron	B
3.	Americium	Am	10.	Bromine	Br
4.	Arsenic	As	11.	Cadmium	Cd
5.	Astatine	At	12.	Calcium	Ca
6.	Barium	Ba	13.	Carbon	C
7.	Beryllium	Be	14.	Cesium	Cs

15.	Chlorine	Cl	35.	Nobelium	No
16.	Cobalt	Co	36.	Oxygen	O
17.	Copper	Cu	37.	Phosphorus	P
18.	Curium	Cm	38.	Platinum	Pt
19.	Fluorine	F	40.	Polonium	Po
20.	Gold	Au	41.	Potassium	K
21.	Helium	He	42.	Promethium	Pm
22.	Hydrogen	H	43.	Proactinium	Pa
23.	Iodine	I	44.	Radium	Ra
24.	Iron	Fe	45.	Radon	Rn
25.	Lead	Pb	46.	Silicon	Si
26.	Lithium	Li	47.	Silver	Ag
27.	Magnesium	Mg	48.	Sodium	Na
28.	Manganese	Mn	49.	Strontium	Sr
29.	Mercury	Hg	50.	Sulfur	S
30.	Neodymium	Nd	51.	Thorium	Th
31.	Neon	Ne	52.	Tin	Sn
32.	Neptunium	Np	53.	Uranium	U
33.	Nickel	Ni	54.	Zinc	Zn
34.	Nitrogen	N			

Unit 1

Assignment Sheet

A. Show the electron configurations of the following elements:

1. Cr	6. S
2. Cl	7. Rh
3. Au	8. P
4. He	9. K
5. Sr	10. Zr

B. Describe the Bohr Theory

C. Discuss the Pauli Exclusion Principle

D. Why are C and Si chemically similar?

E. Compare Electrovalence and Covalence

F. Exponents: Solve the following problems

1. $(1X10^{-24})\quad (6X10^{10})^2\quad (1.5X10^{50})$

2. $\dfrac{(0.000069)^2(16928)^4}{0.0000000001}$

3. $(3)(0.0000009)$

4. $\sqrt[4]{1X10^{16}}$

5. $10^{2/10}$

Unit 2

Atomic Particles and Electromagnetic Radiations

A. The Nature of Electricity

1. Describe the electric charges produced by rubbing glass with silk and hard rubber with fur. Why do these charges seem to be different?
2. Discuss what we mean by positive and negative charges.
3. What is static electricity?
4. What is dynamic electricity?

5. What is a volt?
6. What is an ampere?
7. What is an ohm?
8. Describe the direction of flow of electric current.
9. Differentiate between alternating and direct current.
10. What is a cathode? An anode?
11. How are cathode rays produced?
12. What is the effect of a magnetic field on cathode rays?
13. What are cathode rays?

B. Fundamental Particles

1. Where in the atom is the electron located?
2. Describe the magnitude of the negative electric charge (the electron).
3. What is the mass in grams of the electron?
4. Compare the mass of the electron as compared to the mass of hydrogen.
5. Upon what does the mass of the electron depend?
6. What do we mean by the term rest mass?
7. What is the radius of an electron?
8. What is a positron?
9. What is the mass of a positron?
10. What is the average life of a positron?
11. What happens when a positron and electron unite?
12. What is annihilation radiation?
13. What is the general rule for "anti" particles?
14. What is an antiproton?
15. Describe Roentgen's discovery of the X-ray.
16. Describe the properties of Roentgen's X-ray.
17. What is an anticathode?
18. What are characteristic X-rays?
19. What is the general wavelength of X-rays?
20. Discuss why crystals are used as diffraction gratings.
21. Who discovered radioactivity? How was it discovered?
22. Who first called it "radioactivity"?
23. What are alpha particles?
24. What are beta particles?
25. Compare the penetrating power of alpha and beta particles.
26. What are gamma rays?
27. Who discovered the neutron?
28. Why does a neutron not produce a track in a cloud chamber?
29. Account for the high penetrating power of the neutron.
30. Compare the neutron and antineutron.
31. Discuss Pi, Mu and K mesons. Include their mass and charge.
32. What is a neutrino?
33. What are cosmic rays?
34. In what form do cosmic rays reach the earth?

Unit 3

The Dualistic Nature of Radiant Energy

1. Essentially, what is energy?
2. How can energy be converted from one form to another?
3. What is the result of a very large amount of energy being produced in a very short time?
4. Define radiant energy.
5. How did Newton try to explain light?
6. Discuss the wave theory of light.
7. Why was Newton opposed to the wave theory?
8. How does optical diffraction suggest that the wave theory may be correct?
9. Discuss optical interference and its relation to the wave theory.
10. What do we mean by wavelength? What is the wavelength of red light?
11. How does wavelength control color?
12. What radiations would be invisible to the eye?
13. Discuss the range of electromagnetic waves.
14. How are all these radiations fundamentally the same?
15. What are Hertzian waves? How are they produced?
16. Which color is the most efficient radiation absorber?
17. Discuss the theory of the ideal "black body". Does this exist?
18. Discuss Planck's theory concerning how a body absorbs or emits energy.
19. What is a quantum of energy?
20. Give Planck's formula for determining the quantum of energy for a given frequency.
21. What is Planck's constant?
22. State the formula for the exact relationship between the energy quantum and the wavelength.
23. What is an electron volt?
24. Give the relationship between the electron volt and the erg.
25. What is a kilovolt (kev)? A Megavolt (Mev)?
26. Explain what Einstein meant by the term photon.
27. What is the Compton effect?
28. What happens to X-rays when they interact with electrons?
29. What is meant by wave-particle duality?
30. State deBroglie's equation showing that a particle m, moving with a velocity V, is associated with waves of length λ.
31. What must the size of particles be in order that they exhibit the property of waves?
32. Explain why crystals can be used as diffraction gratings.
33. How did Thompson prove that electrons show wave properties?
34. Give one use of the wave properties of electrons.
35. In respect to wave or particulate properties, how do we refer to electrons? Neutrons? Atoms? Molecules? Light?

36. State and explain Heisenberg's uncertainty principle.
37. What was the theory of ether?
38. What is the velocity of light in miles per sec?
39. What is the velocity of light in cm/sec?
40. Is this velocity a constant?
41. Note carefully the Lorentz equation for the variation of mass with velocity.
42. Why is the above equation taken to be the correct representation of the effect of motion on the mass of an electron?
43. State and discuss the Einstein mass energy equation.
44. Discuss the implications of this equation.
45. Discuss how this equation changed our original concept of the relationship of mass and energy.
46. Why had changes in mass never been detected in chemical reactions?
47. What is an atomic mass unit?
48. How do we calculate the mass of any atom in grams?
49. One atomic mass unit is equal to what amount of energy in electron volts
50. Using the above information, how can you quickly calculate the energy equivalent of any given mass?
51. Correlate the above information using the Einstein mass-energy equation.
52. What is annihilation radiation?
53. When an electron-positron pair annihilate each other, what is formed?
54. How does electron-positron annihilation substantiate the Einstein mass-energy relationship?

Unit 3

Problem Set #1

1. Determine the wavelength of a photon with a frequency of 3×10^5 vps.

2. What is the wavelength of a photon with an energy of 1.5 mev?

3. Visible red light: = 7.6×10^{-5} cm.

   a. Determine frequency
   b. Determine its energy

4. What is the energy in Mev of a B^- particle traveling at 2.86×10^9 cm sec $^{-1}$?

5. Calculate the frequency of a photon which has an energy of 1.99 X 10-8 ergs.

6. What is the wavelength of a 454-gram baseball traveling as a speed of 200 meters/sec.?

7. Calculate the energy of a proton accelerated to 2.5×10^{10} cm/sec.

8. Using the deBroglie formula, prove that the rest mass of an electron is equal to zero.

9. Why must we assume that radiation has a dualistic nature?

10. Calculate the annihilation radiation produced by a proton-antiproton impact.

Problem Set #2

Quantum Mechanics; Relativity

1. If a 5 g ball bearing is accelerated to a velocity of 2.8×10^{8} cm/sec, what will its mass be at that velocity?

2. If the legendary Hiawatha shoots a 30 cm arrow with his magic bow at a velocity of 0.8C, what length will the arrow be at this velocity?

    a. The rest mass of this hypothetical arrow is 50 g. What is its mass at 0.8C?

3. What is the wavelength of a 1 mg mass moving at 2×10^{7} cm/sec?

4. What is the frequency of a 10^{-8} cm gamma ray?

5. What is the energy of a photon with a wavelength of 10^{-7} cm? 10^{-3} cm?

6. How can two photons have different energies, even if their speed is the same, provided they have different wavelengths?

7. What is the wavelength of a photon with a frequency of 10^{-2} vps?

8. Describe the Compton Effect.

9. Using the Einstein equation, explain how we have altered our concept of the relationship of mass and energy.

Unit 4

The Structure of the Atom

1. How did most of the nineteenth century scientists regard the atom?
2. Describe why J. J. Thomson's concept was important, even if it is no longer accepted.
3. Describe the results of Rutherford's experiment in passing Alpha particles through metal foil.
4. How did Rutherford describe this phenomenon?
5. As a result of this experiment, how did Rutherford describe the atom?
6. How can we account for this scattering of alpha particles?
7. Why were such a small number of alphas repulsed?
8. In describing the atom, what is the Z number?
9. Describe the number of positive and negative charges on an atom.
10. About what part of the total atomic weight of an atom is composed of positive charges?
11. How did the above information tell us approximately the number of naturally occurring elements? Is this calculation true?
12. Where is the mass of an atom concentrated?
13. What is the radius of the atomic nucleus?
14. What is the radius of an electron?
15. What actually accounts for the nuclear mass?
16. Of what does an atom mostly consist?
17. Describe the relationship between the number of positive charges on an atom and the atomic number.
18. What is the relationship between the number of electrons and the atomic number?
19. What is an orbital electron?
20. Actually, what is a proton?
21. To which nucleus is the Alpha particle identical?
22. What is an ion?
23. How is an ion formed?
24. What is an ion pair?
25. What is a neutron? Describe its properties.
26. Now describe the three fundamental particles which make up an atom.
27. What do we mean by the word nucleon?
28. What is the A number of an atom?
29. What is the Z number of an atom?
30. How can you calculate the number of neutrons in a nucleus, using the A and Z numbers?
31. What is an isotope?
32. How can we change one atom into an atom of another element?
33. What do we mean by binding energy?

34. Discuss the binding energy of an alpha particle.
35. What does a high binding energy indicate? A low binding energy?
36. Discuss the concept of electron energy levels.
37. How can we cause electrons to change their energy levels?
38. What must an electron lose to drop from a higher to a lower energy level?
39. What is the ground state of an electron?
40. What is the excited state of an electron?
41. What is a characteristic X-ray?
42. How may characteristic X-rays be used to identify unknown atoms?
43. What is bremsstrahlung?
44. Explain the concept of nuclear energy levels.
45. What type of radiation is given off by changes in nuclear energy levels?
46. What is nuclear "spin"?

Unit 4

Problem Set

1. Determine the nuclear radius of C^{14} (A = 14.007682) and Ra^{222}(A=222.0845).

2. Determine the volume of the following nuclides:

   a. $_1H^1$

   b. $_1H^2$

   c. U^{235}

   d. W^{186}

   e. Er^{168}

3. What is the nuclear radius of a proton?

4. What is the radius of the nucleus of an atom (A=26) when it is accelerated to 2.8×10^{10} cm sec^{-1}?

Unit 5

Radioactive Elements

1. Who first discovered radioactivity? When?
2. What methods of detection were used by these early workers?
3. Describe the piezoelectric device used by Dr. Curie to undertake quantitative measurements of radioactivity.
4. Compare the activity of Polonium with Uranium.
5. Why was Radium similar in its chemical properties to Barium?
6. How much Radium was secured by the Curies from the ton of pitchblende ore they were given?
7. Discuss the number of radioelements now known.
8. What is Uranium X?
9. Draw and discuss the decay - recovery curves of Thorium and Thorium X.
10. Discuss in detail Rutherford and Soddy's Theory of Radioactive Disintegration.
11. How does this explain Radium X and Thorium X?
12. What was the cause of the "Radium induced emanations" first described by the Curies?
13. How do physical conditions affect the rate of radioactive disintegration?
14. How did Lord Rutherford interpret the results of the above question?
15. Does the fact of radioactive decay disestablish our interpretation of an element? Explain.
16. How may radioactive decay products be separated?
17. What is a "carrier"?
18. What is used as a carrier for Polonium, Barium, Radium? Why?
19. What are parent and daughter nuclides?
20. Describe the recoil method of nuclide separation.
21. This method may be used with which type of radioactive decay?
22. What do we mean by the statement that radioactivity diminishes in an exponential (logarithmic) manner?
23. State and explain the formula concerning radioactive decay.
24. Why do we use the negative sign in the above equation?
25. What is the radioactive decay constant?
26. Give the equivalent exponential form of the above equation. (decay equation)
27. Discuss the factor used to convert natural to conventional logarithms, and give the converted decay equation.
28. What is the minimum change of activity which will work in the above equation? Is this satisfactory?
29. How may the mean or average life of an atom be calculated from the half-life?
30. Can you tell exactly which atoms will disintegrate within any given time?

31. Give and discuss the equation for radioactive equilibrium.
32. Explain the equation for radioactive equilibrium of any decay chain nuclide.
33. What does this show concerning the ratio of the amounts of any two members of a disintegration series?
34. Discuss the concept of half-life.
35. How may half-life be calculated from the decay constant?
36. Name and describe the three natural radioactive series.
37. For what types of radioelements are decay rates difficult to calculate? Why?

Problem Set 1 - Half-Life

DATE	TIME	COUNT RATE OF SAMPLE
27 June	1:35 PM	8754 c/m
27 June	4:50 PM	7553 c/m
28 June	8:05 PM	3808 c/m
28 June	3:20 PM	2750 c/m
29 June	9:50 AM	1195 c/m
30 June	8:20 AM	437 c/m
30 June	4:35 PM	300 c/m
1 July	9:50 AM	138 c/m
1 July	3:35 PM	105 c/m

CALCULATE THE STANDARD DEVIATION, AND THEN GRAPH THIS INFORMATION ON NORMAL AND SEMI LOG PAPER. FROM THE SECOND GRAPH, CALCULATE THE DECAY CONSTANT AND THE HALF-LIFE.

Problem Set 2

Experimental Data

Half-Life Determination

DATE	I^{131}	P^{32}
1/11	3562	1048
1/14	2760	8673
1/15	2612	8503
1/16	2383	8042
1/17	2287	7850
1/18	2088	7342
1/21	1542	6401
1/23	1322	5794
1/24	1226	5503
1/25	1166	5199
1/29	819	4540
1/30	737	4166
1/31	684	3942
2/1	600	3832
2/5	512	3185
2/6	403	3052
2/7	385	2769
2/8	343	2797
2/11	255	2397
2/12	263	2274

Determine the half-lives both graphically and arithmetically. Determine the Lambda values.

What is the mean life of the atoms of each isotope?

Define the following: Biological half-life, effective half-life.

Problem Set 3

Experimental Half-Life

DATA

Date	Sample #1	Sample #2
2/6	3356	3742
2/7	2542	2905
2/10	2590	2827
2/11	2260	2587
2/13	1983	2069
2/14	1857	1990
2/17	1300	1473
2/18	1269	1326
2/20	1034	1187
2/21	996	1053
2/25	606	750
2/26	621	669
2/27	600	611

FIND: Half-Life =

λ =

Unit 6

The Measurement of Nuclear Radiations

1. Upon which discovery of Becquerel are some of the most useful procedures for the detection of radiation based?
2. Why are nuclear radiations also called ionizing radiations?
3. How do radiations cause ionization?
4. What is an ion-pair?
5. What is specific ionization?
6. How can we increase ionization for particles of the same mass?
7. For particles of the same energy, how does specific ionization change with speed?
8. Compare the specific ionization of an alpha with a beta of the same energy.
9. State the reason for the above answer.
10. What is total ionization?
11. Upon what is total ionization dependent?
12. How do gamma rays and other electromagnetic radiations produce ionization?
13. Would the specific ionization of a gamma ray be high or low? Explain why.
14. Do the same for the total ionization caused by a gamma ray.
15. Upon which principle do most electronic detectors of radiations operate?
16. In the above detectors, upon what does the size of the current pulse depend?

A. The Ionization Chamber

1. Explain how the speed of the ions toward the electrodes varies with the applied potential (voltage).
2. For what particles can the ionization chamber be used?
3. Sketch and discuss the construction of an ionization chamber.
4. What is an integrating ionization chamber?
5. What is a non-integrating ionization chamber?
6. Why is the ionization chamber an excellent instrument for counting alphas, protons, and neutrons?
7. What is a scaler? What is its purpose?
8. How does the quartz-fiber electroscope operate?

B. The Proportional Counter

1. What is the Townsend Avalanche?
2. What is the gas-amplification factor?
3. What gases are used to fill proportional tubes?

C. Geiger-Muller Counters

1. Diagram the construction of a G-M tube.
2. Why is a high potential maintained in the tube?
3. Describe the difference in the avalanche in the proportional and G-M counters.
4. What is the G-M operating voltage range?
5. Explain the problem of resolving consecutive impulses in this type of tube.
6. What do we mean by quenching?
7. What may be used to quench the tube?
8. What limits the life of self-quenching tubes?
9. Why are chlorine-quenches tubes superior to organically-quenched tubes?
10. What is resolving time?
11. What is a scaler-ratemeter?
12. For what particles are G-M tubes usually used?
13. What is meant by the geometry of a sample?
14. Upon what general principle do scintillation counters operate?

D. The Wilson Cloud Chamber

1. How do ionizing radiations affect the condensation of supersaturated vapor?
2. What happens when an ionizing particle enters the saturated vapor?
3. What are condensation nuclei?
4. What is a cloud track?
5. Describe the tracks of alpha particles.
6. What liquid is presently used to form a saturated vapor in cloud chambers?
7. Describe the track of an electron (beta particle).
8. Describe the diffusion cloud chamber.
9. Describe how particle tracks affect a photographic film.
10. Compare the track lengths of film plates to those of cloud chambers.

Unit 7

Particle Accelerators

1. Define the term "transmutation".
2. How did the development of modern ideas about the atom change our thinking about the possibility of achieving transmutations?
3. Who achieved the first deliberate artificial transmutation?
4. Exactly what were Rutherford's results?
5. What elements emit protons when bombarded with alpha particles?
6. As a general rule, what do nuclear reactions involve?

7. Why was the Cockroft-Walton machine historically important?
8. Diagram and label the Van de Graaff electrostatic generator.
9. Describe how this machine works.
10. What voltages have been reached with this apparatus?
11. Name one important advantage of this machine.
12. Describe the construction of the drift-tube type of linear accelerator.
13. Describe the construction of the cyclotron.
14. What forces the particles to move in a cyclotron?
15. How do these particles move? (Describe their path).
16. How are the radius of the path and the particles velocity related?
17. What is the function of the oscillator?
18. Which accelerator is used for electron acceleration?

To the Teacher:

Due to the complexities of the other types of accelerators, guide questions would be needlessly complex. It is suggested that you prepare simple lectures covering the betatron, electron synchrotron, proton synchrotron and others. The texts listed in the bibliography will give you the desired information.

Unit 8

Nuclear Fission

1. What property of nuclear fission enables it to be self-sustaining?
2. What do we mean by a fissile isotope? Name a few.
3. In fission, what happens to the fissile isotope?
4. In Uranium fission, what amount of energy is liberated?
5. What produces this energy?
6. What weight in A.M.U. is destroyed here?
7. Calculate the amount of energy created here, using the formula Emev=M x 931.
8. Now calculate this using the Einstein equation.
9. What is binding energy?
10. Give the total energy released by the fission products of one Uranium atom.
11. Discuss the approximate distribution of the fission fragments discussed above.
12. Draw and describe the curve for the isotopes produced by U^{235} fission.
13. In the curve you have just drawn, why did you plot mass numbers instead of atomic numbers?
14. In how many different ways may the uranium nucleus split?
15. From where do the neutrons thrown off in fission come?

16. What are prompt neutrons?
17. What are delayed neutrons?
18. How may the nuclear mass produce instability?
19. The theory of the liquid drop nucleus will be discussed in class.
20. Discuss the concept of fission due to nuclear energy levels.
21. Define the critical energy for fission.
22. In Uranium fission, what happens to the electrons? What effect does this have on the fragments?
23. What type of activity do the fission fragments show? Why?
24. What is a fission decay chain?
25. How many possible fission fragments are there?
26. How many radionuclides (radioisotopes) may be produced by the decay of these fragments?
27. How much time is required for the actual fission process?
28. Why is Uranium-238 not used to make the atomic bomb?
29. Why was Uranium-235 selected?
30. How much energy is liberated by the fission of 1 kilogram (2.2 lbs.) of U-235?
31. What other element was considered to be an alternate to Uranium for the bomb?
32. What is a moderator?
33. What substances are suitable for moderators?
34. What is the reproduction factor of a fission system?
35. What do we mean by the critical size of a system?
36. What is a subcritical size? Supercritical size?
37. What is a neutron reflector?
38. How probable is it that a nuclear reactor will explode?
39. What is a control rod? Of what material are control rods composed?
40. How is the power of a reactor increased?
41. How is a reactor shut down?
42. How is a reactor started up?
43. How is Plutonium-239 produced in a reactor?
44. How would the Uranium-239 and Plutonium-239 be separated?
45. Compare the nuclear pile and the nuclear bomb.
46. What is the result of a large amount of energy released in a short time within an enclosed space?
47. What are the two main requirements for a fission bomb?
48. Why is the process of slow neutron fission undesirable for a bomb?
49. Why is it impossible to prevent a chain reaction in a supercritical mass?
50. How is this criticality problem solved?
51. Describe the gun barrel bomb.
52. Describe the implosion or critical density bomb.
53. How does the reflector in a bomb decrease the critical mass?
54. What was the explosive power of the first A-bomb?

55. What temperature accompanies an atomic explosion?
56. Describe the reasons for the effects of the A-bomb.
57. To what is the liberation of energy in the fission bomb due?
58. How does this relate to the fusion of light nuclei?
59. What is a thermonuclear reaction?
60. How can two nuclei overcome the electrostatic repulsion between their two positive charges?
61. How much energy is required to make the nuclear reaction occur?
62. What temperature must be reached to be equivalent to this energy?
63. What is plasma?
64. Describe the Carbon-cycle fusion reaction.
65. Discuss in detail the proton-proton fusion reaction.
66. What nuclei are suitable for fusion reactions on earth?
67. What weight of deuterium is available on earth?
68. How are the temperatures necessary for fusion attained?
69. Discuss the construction of the H-bomb.
70. In outline, of what does a nuclear reactor consist?
71. What are the components of the reactor core?
72. Describe the two methods of reactor control.
73. What must be taken into consideration in designing a reactor?
74. Define the term thermal reactor.
75. How are neutrons in such a reactor slowed down?
76. What is the main advantage of the thermal reactor?
77. Discuss the major drawback of a thermal reactor.
78. What is a fast reactor?
79. What are the disadvantages of a fast reactor?
80. What is a "breeder reactor"?
81. What is an intermediate reactor?
82. Of what elements may the nuclear fuel be composed?
83. What percent of Uranium is U-235?
84. Discuss which isotopes may undergo fission.
85. For what is Th-232 used?
86. Discuss solid reactor fuel elements.
87. Discuss radiation damage to reactor fuel elements.
88. What is a reactor poison?
89. What are the basic requirements for a moderator?
90. What materials are suitable for moderators?
91. Discuss why water is commonly used as a moderator.
92. What is one drawback of water as a coolant?
93. What is the best material available as a neutron moderator?
94. Why is beryllium used as a moderator in special cases only?
95. What form of carbon is used as a moderator?
96. What materials may be used as reactor coolants?
97. What is a heat exchanger?
98. What is a regenerative reactor?
99. Discuss the production of Uranium-239 in a regenerative reactor.

100. What is a breeder reactor?
101. How is it possible to increase our stockpile of Plutonium-239 in a breeder reactor?
102. How may the fertile material be placed in a reactor to produce Plutonium-239?
103. Name the three types of reactors.
104. What is a research reactor?
105. Discuss and describe a thermal column.
106. What is a spent fuel element?
107. Of what use are spent fuel elements?
108. How may we dispose of the fission waste products?

Problem Set

Calculate the energy release per fission event for the following reactions:

a. $^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{95}_{42}Mo + {}^{189}_{57}La + 2\,{}^{1}_{0}n + 7\,{}^{0}_{-1}e$

b. $^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{140}_{56}Ba + {}^{89}_{36}Kr + 5\,{}^{1}_{0}n$

c. $^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{150}_{60}Nd + {}^{77}_{32}Ge + 9\,{}^{1}_{0}n$

Nuclear Masses:

$^{235}U = 235.049$

$^{95}Mo = 94.9058$

$^{139}La = 138.9061$

$^{1}_{0}n = 1.0087$

$^{0}_{-1}e = 0.00055$

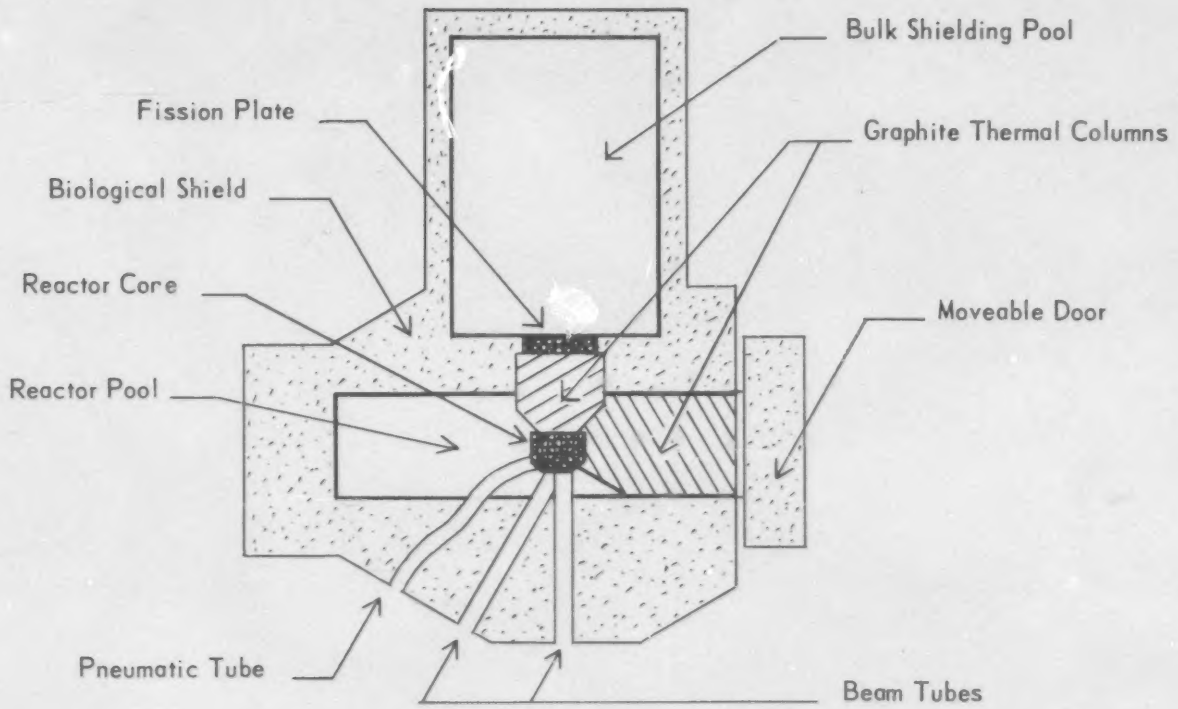
$^{140}Ba = 139.9544$

$^{89}Kr = 88.9448$

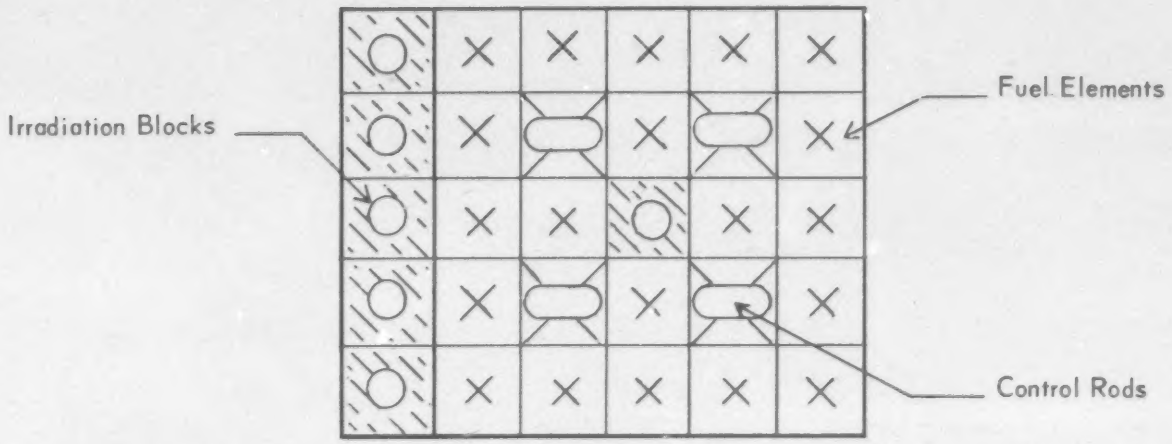
$^{150}Nd = 149.9679$

$^{79}Ge = 76.9484$

A Typical Nuclear Reactor



The Reactor Core



FISSION AND REACTORS

Reading Assignments

A. U.S.A.E.C. Division of Technical Information Booklets

1.	Atomic Fuel	John Hogerton
2.	Plutonium	W. N. Miner
3.	Research Reactors	N. H. Jacobson
4.	Controlled Nuclear Fusion	S. Glasstone
5.	Nuclear Propulsion for Rockets	Univ. of Calif.
6.	Nuclear Reactors	Univ. of Calif.
7.	Controlled Thermonuclear Fusion	Univ. of Calif.

B. Assorted Pamphlets

1. Argonne National Laboratory
2. Nuclear Research Center: Battelle Memorial Institute
3. Dresden Station

C. Texts

1. Glasstone: Sourcebook on Atomic Energy; pp. 385-480
2. Optional: Humphreys and Beringer

Atomic Physics; pp. 354-367

Unit 9

Fusion

1. Prior to 1939 which method of releasing nuclear energy was considered the most promising?
2. Why does the fusion of light nuclei result in a liberation of energy?
3. How can nuclei of low mass number be brought together in order to have them undergo fusion?

4. To be of practical value, what properties must fusion reactions possess?
5. Discuss the Hemholtz theory concerning solar energy product. Why is it now rejected?
6. Discuss Eddington's two alternate theories of solar energy production.
7. What are thermonuclear reactions?
8. What property must particles possess in order to overcome the electrostatic repulsion barrier in order to undergo fusion?
9. What energy is required to make nuclear reactions of hydrogen isotopes occur?
10. What temperature would be required to achieve this energy?
11. What is plasma?
12. What is the Maxwellian distribution of energies among the molecules of a gas?
13. How would this Maxwellian distribution affect a plasma?
14. Give the nuclear equations for and discuss the carbon cycle.
15. Give the nuclear equations for and discuss the proton-proton chain.
16. What factor determines which of the above two reactions occurs?
17. Which of these two reactions predominated in the sun?
18. What weight of the sun's hydrogen is converted into helium annually?
19. What will happen to the sun after five percent of its hydrogen has been consumed? How far in the future will this be?
20. Why would the carbon cycle and proton chain be only of limited value for a bomb?
21. Which isotopes were chosen as showing the most promise to be fusile?
22. What is the ratio of deuterium to hydrogen in all natural waters?
23. What was the 1967 price of heavy water? (deuterium oxide)
24. Why are accelerators not used as a means of producing fusion?
25. Discuss differences in control of the fusion reaction in the bomb and the fusion reactor.
26. What conditions are necessary for a self-containing nuclear system?
27. What are the problems of plasma confinement?
28. What is a "magnetic bottle"?
29. Describe the pinch effect.
30. Discuss the stellarator.

Unit 10

Radiation Health Physics

1. Describe the results of Pierre Curie's voluntary exposure to Radium emanations.
2. When did workers begin to pay attention to radiation hazards?
3. Which agency is now responsible for establishing radiation exposure limits in the U.S.?
4. What is the function of Health Physics?

5. What are the responsibilities of the health physicist?
6. How do neutrons cause biological damage?
7. How do radiations affect body cells?
8. How do damaged body cells affect the circulatory system?
9. Describe the effects of radiations on the process of mitosis.
10. What is the relationship between radiation exposure and the growth of cancers?
11. Why may individuals become unconsciously exposed to excessive radiation exposure?
12. What is the effect of very large doses of radiation upon the human system?
13. Describe in detail the effects of prolonged (chronic) exposure to radiation.
14. Describe in detail the results of acute overexposure to radiation.
15. What radiation effects may not become apparent for years following acute doses?
16. Why is susceptibility to infection a symptom of radiation sickness?
17. To what are the effects of radiation upon the blood due?
18. What organs are considered to be radiosensitive? Radioresistant? Intermediate?
19. Which elements are bone seekers?
20. Why are these bone-seeking elements harmful?
21. What is the main consideration in determining the biological hazard of a given element?
22. Explain the meaning of biological half-life.
23. Describe the meaning of effective half-life.
24. What type of elements present the greatest potential internal hazard?
25. Give the example of the above question given by Glasstone, using I-131 as the example.
26. Define the Roentgen.
27. Define the Rad.
28. Define the Rep.
29. Define the Rem.
30. Discuss the RBE.
31. Explain the factors determining the RBE for a given radiation.
32. Define the type of dose intimated by the Rem, Rad, and Roentgen.
33. What is the reason for the recovery by the body from small doses of radiation?
34. List the sources of background radiation.
35. In the U. S., what is the dosage from natural background?
36. What is the mpd (maximum permissible dose)?
37. What is a normally lethal dose of radiation?
38. Discuss the difficulty of assessing total body dosage?
39. Define the mpd in Rems.
40. What is mpc (maximum permissible concentration)?
41. List the mpc for: Plutonium-239; Strontium-90.
42. Describe the construction of the film badge.

43. How are neutrons detected by a film badge?
44. Describe the pocket air dosimeter.
45. How are neutrons detected by the air dosimeters?
46. Describe the pocket gamma dosimeter.
47. Why do we take urine samples from radiation workers?
48. Discuss the blood tests used to diagnose overexposure.
49. Why is lead a poor absorber for high energy betas?
50. Discuss the method used for gamma absorption.
51. What type of concrete is used for reactor shielding?
52. What is a gene?
53. How do the genes influence heredity characteristics?
54. What is a mutation?
55. Discuss the three possible ways in which radiations may cause mutations.
56. Discuss the relationship between the frequency of gene mutations and the gonadal dose.
57. Discuss the types of deleterious mutations.
58. What is the dosage which should double the rate of spontaneous mutations?
59. Differentiate between somatic and genetic mutations.
60. How are gamma rays being used to attempt to produce improved plant species?

Unit 11

Radioisotope Applications

1. Why have radioisotopes only recently come into use as a research tool?
2. Compare the chemical properties of all the isotopes of a given element.
3. How does a trace of a radioisotope label a compound?
4. How was Carbon-14 used to trace plant respiration?
5. How were isotopes used to explain fertilizer uptake?
6. How were they used to explain the mechanics of blood mixing after transfusions?
7. How was Oxygen-18 used to explain photosynthesis?
8. Describe the first application of a radioisotope to biological research.
9. What is a stable isotope?
10. Why, until recently, was the use of isotopes restricted?
11. How many stable isotopes are now available?
12. How are these stable isotopes obtained?
13. What is the usual source of radioactive isotopes?
14. How do we obtain radionuclides which cannot be conveniently derived by placing stable isotopes in a neutron flux?
15. Why are radioisotopes rather than stable isotopes often selected to apply in a research problem?

16. Why are alpha emitters unsatisfactory for use as biological tracers?
17. How does half-life determine the usefulness of an isotope?
18. What is the relationship between the life of a radioisotope and the energy of the emitted particle?
19. What is the greatest advantage of a stable isotope?
20. How are stable isotopes detected?
21. Why is it difficult to work with the radioactive isotopes of nitrogen and oxygen?
22. Why is tritium difficult to work with in living organisms?
23. Describe the production of Carbon-14 and Carbon-11.
24. Describe the nuclides available for biological research.
25. Discuss the rate of disintegration of a radioelement.
26. What is the smallest amount of activity which can satisfactorily be counted?
27. Give and explain the formula for determining the minimum number of radioactive atoms which can be conveniently detected.
28. How can the above number be converted into grams of an isotope?
29. How is this weight of an isotope related to mass number and half-life?
30. Define specific activity. How is it expressed?
31. What is a labeled compound?
32. What is biosynthesis?
33. What types of compounds are labeled by biosynthesis?
34. How are labeled acids produced?
35. Describe the density methods of determining the presence of deuterium.
36. What is autoradiography? Radioautography?
37. What are the main uses of isotopic tracers in biology and chemistry?
38. Which radioisotopes have been used to perform research on the blood?
39. Describe the use of radioisotopes to show restricted circulation.
40. How has this isotope been used to show heart action?
41. What is preferential absorption? How is this important?
42. How is Iodine-131 used to diagnose hyperthyroidism?
43. How may this isotope be used to treat cancer of the thyroid?
44. How may isotopes be used for tumor location?
45. Describe the use of Phosphorus-32 for the treatment of polycythemia and leukemia. Is this method an actual cure?
46. Why is Cobalt-60 replacing both Radium and X-rays for cancer treatment?
47. Discuss several industrial applications of isotopes.
48. Describe isotopic dilution analysis.
49. Describe activation analysis.
50. Describe tracer analysis.
51. Describe the use of an isotope to show the new standard of length.
52. Explain Carbon-14 and Tritium dating.
53. How may isotopes be used to eliminate static electricity?
54. How have radiations been used to improve plastics?
55. Why has cold sterilization of foods by radiation been abandoned?
56. Describe the beta current electric cell.
57. Describe the other nuclear electric cells.

IX LABORATORY EXPERIMENTS AND TECHNIQUES

The fact that most high school laboratories will not have more than one or two Scaler-Ratemeters available due to their high cost and to the fact that they are not standard equipment will be a major inconvenience, making it necessary to have only a few students using the Scaler at any one time.

One solution to the problem is to separate the class into a number of laboratory groups of perhaps three or four students, with each group performing a separate experiment during any one laboratory period. This necessitates a major scheduling task, but it is resolved with a little effort. The teacher can circulate among the groups, giving advice and direction where necessary. It is necessary to duplicate the experimental procedures and to give the proper directions to each group ahead of time. These directions should outline the experimental procedures and include related questions concerning the work in order to attempt to develop further insight concerning the experiment.

It is recommended that a formal written laboratory report be submitted two days following any experiment. This report should include the purpose of the experiment, the procedures, the observations, the conclusions, and the related questions, in that order. The written report gives more reason to the student to make careful manipulations and observations, as

well as requiring further thought and study concerning the experiment, resulting in increased learning.

The following are a number of laboratory experiments which may be included in this course of study. The first experiments must necessarily concern the operation of the equipment and the properties of radioisotopes, while the last group may be devoted to the applications of radioisotopes. It should be emphasized that these experiments should be subjected to continuous revision. Many further experiments may be found in the various Atomic Energy Commission booklets or laboratory manuals available. A list of these booklets and manuals is included in Chapter IV.

LABORATORY GUIDE SHEETS

EXPERIMENTAL: CHEMICAL AND PHYSICAL CHANGES

1. Mix an equal volume of iron and sulfur (5g ea.) together on a piece of paper. Make certain that the iron is evenly distributed in the sulfur. Place half in a test tube.
2. Now add 20ml of carbon disulfide and shake thoroughly. Filter your solution.
3. Evaporate the liquid part, and describe what results.
4. Now take the second portion of your mixture and pass a magnet over it. Describe your results.

*5. Remix the iron and sulfur and add 3gm of sulfur. Place it in a crucible and heat it for 4 minutes.

*CAUTION! The carbon disulfide vapors must be cleared from the room before the burners are ignited, or a fire and/or explosion may result.

6. Repeat steps #2, 3, and 4. Describe your results.
7. Related questions:
    a. What is a mixture? Must a mixture contain definite proportions of its components?
    b. What is a compound? Must a compound contain definite proportions of its components?
    c. Contrast chemical and physical changes.
    d. Was the iron and sulfur combination in part 1 a compound or a mixture? Explain fully how you reached your conclusion.
    e. Do the same for the combination after you heated it.

EXPERIMENTAL: DIRECT COMBINATION AND DECOMPOSITION

1. Carefully weigh your crucible. Then fill it about half full of iron filings, and weigh it again. Determine the weight of the iron filings.
2. Heat the crucible and filings for ten minutes, making sure that it becomes red hot.
3. Cool the crucible and contents and weigh them again. Determine the weight of the crucible contents.
4. Explain any possible difference in weights. Would you suspect that any chemical combination has taken place? If so, explain why.
5. Related questions:
    a. What is direct combination?
    b. Why is there a difference in weight before and after heating?
    c. What is an element? A compound?

d. What compound has been formed in your crucible?

e. Calculate the molecular weight of this compound.

1. Add about 5 drops of H_2SO_4 to a 250 ml flask of water.
2. Place this solution in the electrolysis apparatus, and connect the wires to the power supply.
3. Turn the power supply to the maximum voltage, and allow it to run for about 15 minutes. Describe what happened.
4. Notice that your gas on one side of the tube is twice the volume of the gas on the other side. Fill an inverted test tube with this gas. Hold a burning splint near the mouth of the tube. A "pop" is a positive test for Hydrogen.
5. Hold a smoldering splint near the second tube, and release the gas. Describe what happens. What gas is this?
6. Related questions:
   a. Define decomposition
   b. What is the percent by weight of Hydrogen in water?
   c. Describe the electrolysis of water.
   d. Why was the H_2SO_4 added to the H_2O?

EXPERIMENTAL: THE SIZE OF A MOLECULE

1. Prepare a solution of $1.0cm^3$ of oleic acid in denatured alcohol and dilute to $400cm^3$. Pour H_2O to a depth of about 1cm. in a large shallow tray. Dust the surface lightly with Lycopodium powder.

2. With a medicine dropper, place one drop of the oleic acid solution on the water surface. This pushes the surface dust outward so the area of the oleic acid layer is visible.
3. Measure the diameter of the oleic acid layer and calculate its area.
4. Experimentally determine the number of drops of oleic acid solution per cubic centimeter, and calculate the volume in the drop of solution used. This is the volume of the surface layer. Using this volume and the area of the layer, calculate its thickness.
5. Assuming the oleic acid molecules to be cubes forming a layer one molecule thick, calculate the volume of one molecule.
6. The mass of oleic acid is 0.895 gm/cm^3 and one mole has a mass of 282.5gm. Calculate the volume occupied by one mole of oleic acid.
7. Calculate the number of molecules in a mole of oleic acid. How close is your result to the Avogardro number?
8. Related questions:
    a. Why are we justified in assuming that the oleic acid layer on water is one molecule thick?
    b. How well does your determination of Avogardro's number compare with the accepted value?
    c. What are some sources of error in this experiment?

EXPERIMENTAL: STATIC ELECTRICITY

1. Rub the ebonite rod with the piece of cat's fur and bring it close to the suspended pith ball. Result?

2. Allow the pith ball momentarily to touch the ebonite rod. Explain the movement of the pith ball.
3. Rub the glass rod with silk and repeat the procedure in steps 1 and 2. Explain your results.
4. How is the pith ball charged when it is repelled by the glass rod?
5. If a charged ebonite rod is brought near such a charged pith ball, what should happen? Try it and see if this is what actually happens. Explain your results.
6. Suspend a charged ebonite rod in its hanger. Bring a second charged ebonite rod near one end and then the other. Describe your results.
7. Now bring a charged glass rod near each end of the suspended ebonite rod. Explain your results.
8. Is the charge the same on both ends of the suspended rod?
9. Does the second charged rod have the same charge?
10. Related questions:
    a. What conclusion do you draw regarding the behavior of electric charges to each other?
    b. How do like charges affect each other?
    c. How do opposite charges affect each other?
    d. How can you prevent a body from accumulating a static charge?

EXPERIMENTAL: DETERMINATION OF THE OPERATING VOLTAGE OF A GEIGER-MULLER COUNTER

1. Place your radioisotope sample in the tube mount on the second shelf. Allow it to remain in exactly this position for the entire experiment.

2. Adjust your voltage to 200V, and take a two-minute count. Record this reading, corrected for background, as counts per minute.
3. Increase your voltage by twenty volts, and take a two minute count at this voltage.
4. Take a series of two minute counts, increasing your voltage by twenty volts for each count. Record each count in terms of counts per minute.
5. You will notice that your counts will increase sharply, level off, and then rise sharply again. As soon as the count begins to make this second sharp rise, decrease the voltage and stop counting.
6. Plot your data as a function of the counts per minute against the voltage.
7. From the graph, determine the threshold and the operating voltage of your tube.
8. Related questions:
    a. Discuss the construction of a Geiger tube.
    b. Why must a minimum voltage be reached before the tube begins to operate?
    c. What is threshold voltage?
    d. Why is it always necessary to keep the same operating voltage when counting?

EXPERIMENTAL: CALCULATION OF THE DEAD TIME
OR RESOLVING TIME OF A GEIGER-MULLER COUNTER

1. Place the sample in the tube mount and record its activity. Repeat this twice more, and average your three counts.
2. Now place the second sample beside the first, placing it as close as possible without disturbing the first sample. Take three counts and record the average.
3. Now remove the first sample without disturbing the second. Count the second sample as you did the first, and record.
4. You will notice that the sum of the two counts for the individual samples is higher than that taken of the two samples simultaneously. This is due to the dead time, (resolving time, paralysis time), of the counter.
5. Now calculate the dead time, using the formula:

$$Ti = \frac{N_1 + N_2 - N_s}{2N_1N_2}$$

Where: Td = dead time, N_1 = activity of the first sample, N_2 = activity of the second sample, and N_s = activity of the combined samples.

6. Related questions:
   a. Discuss the reasons for counter dead time.
   b. How may this affect your future experiments?

EXPERIMENTAL: STATISTICS

1. Take a background count for a five minute period. Compute background in counts minute - 1, and correct all subsequent readings.
2. Place your first sample on the tube mount and take a series of fifteen one-minute counts without moving your sample. Correct for background and record these counts.
3. Were all these counts the same? Account for any seeming discrepancies.
4. What is standard deviation? Calculate your average count and the standard deviation.
5. What is meant by the most probable count? What is your most probable count?
6. Correct the above counts for dead time.
7. Related questions:
    a. What might be the source of background radiation?
    b. Why do your counts vary?
    c. What were your highest and lowest counts?

EXPERIMENTAL: VARIATIONS IN THE COUNTING RATE WITH INCREASING DISTANCES OF THE SAMPLES FROM THE TUBE

1. Place your sample of P-32 on the highest counting shelf. Carefully measure the distance from the tube to the sample. Now count the sample.
2. Do this for each shelf of the tube holder, recording distances in cm, and corrected counts per minute.

3. On graph paper, plot the counts min.$^{-1}$ against the distances recorded.
4. Discuss your results.
5. Related questions:
    a. What might the reasons be that the number of particles reaching your tube varies with distance?
    b. What might absorb the beta particles before they reach the tube?
    c. From the above experiment, sketch what the column of radioactive particles must look like.

EXPERIMENTAL: IONIZATIONS INDUCED BY RADIOACTIVITY

1. Charge the Landsverk Electroscope and adjust it so that the fiber shadow reads zero.
2. Place your alpha emitter (Radium D and E) in the chamber, and start your stop watch.
3. Determine the rate of drift of the image of the fiber in divisions/minute.
4. Repeat the above experiment with the second planchette. Compare its activity with that of the first sample.
5. Count both above planchettes on the top shelf of the Scaler Ratemeter. Was your decision under #4 correct?
6. Related questions:
    a. Describe the construction of the Lauritzen Electroscope.
    b. What will cause the electroscope to discharge?
    c. How do radioactive particles lose their energy?
    d. What is a pocket dosimeter?

e. What is meant by the specific ionizations of a particle?

f. What is total ionization?

g. Compare alpha, beta and gamma radiations as to their total and specific ionizations.

h. Would an alpha emitter or a gamma emitter be the most dangerous if accidentally swallowed? Why?

COSMIC RAYS

1. Turn on the portable survey meter with side-window tube. Close the tube window to exclude alpha and beta particles.
2. Using the stop-watch, count the number of particles hitting the tube for a two-minute period. Repeat this for ten-two minute counts.
3. Calculate the average number of particles striking your tube per minute.
4. Related questions:

   a. What are cosmic rays?

   b. From where do the cosmic rays come?

   c. Are these particles penetrating? How do you know this?

EXPERIMENTAL: RADIOACTIVE DECAY
GROUP PROJECT

1. You will be given a radioactive sample. The count for this sample will be recorded, corrected for background, for thirty consecutive days (except Saturday and Sunday). The data will be supplied to the entire class.

2. On semi-log paper, plot the recorded c/m against the time in days.
3. Allowing for standard deviation, draw a straight line which will intersect the greatest possible number of counts.
4. From this graph, determine the half-life of the radioactive sample.
5. Related questions:
    a. Why must the counts on each day be corrected for background?
    b. Why must the readings be taken from the same counter shelf?
    c. What is half-life?
    d. What is a daughter isotope?
    e. In cases of radioactive contamination, why is a knowledge of half-life necessary?
    f. At twelve noon, September 12, 1961, a sample of P32 contains 1000 atoms. How many P32 atoms will remain on September 26, 1961, at 12 noon?
    g. State the half-lives of: a. C^{14} b. Fe^{59} c. Co^{60} d. Sr^{90}.

EXPERIMENTAL: THE WILSON CLOUD CHAMBER

1. Break the dry ice into small pieces, and place it in the pan. Place the chamber on top of the dry ice.
2. On the bottom blotter of the chamber pour 5ml of the methyl alcohol provided. Place the side blotters of the chamber in place and place the cover in position.
3. Place the lamp so that the beam of light passes through the lower 1/3 of the chamber, in a direction toward the radioactive source.

4. Attach the electrodes of the chamber clearing field to the voltage supply.
5. Insert the alpha emitter in the hole in the side of the chamber. Observe the thick, short, straight track.
6. Now insert the beta emitter and observe its tracks.
7. Now insert the unknown sample which you will be given into the chamber. Determine from the tracks the type of radiations which are being emitted.
8. Related questions:
    a. Describe the construction and operation of the Wilson Cloud Chamber.
    b. Compare the tracks of alpha and beta particles.
    c. What type of tracks did your unknown sample emit? Upon what did you base your conclusions?
    d. Did you see any evidence of any particles other than your samples in the chamber? If so, what might have been the origin of these particles?

EXPERIMENTAL: BETA ENERGY

1. Take and record on your data sheet the background count. Correct all subsequent counts for background.
2. Place your sample of P32 in the third shelf of your counter. Allow it to remain here for the entire experiment.
3. Determine the activity of your sample. Now place the $1 mg/cm^2$ absorber in the first shelf and make your reading. Count and record the activity for each of the absorbers in the kit, or until you get no activity penetrating the absorber.

4. On semi-log paper, plot the activity in counts per minute against the absorber thickness in mg/cm^2. Discuss the resulting graph.
5. Related questions:
    a. What is a beta particle?
    b. With what energies may beta particles be emitted?
    c. When a beta particle passes through matter, how does it lose its energy?
    d. What is bremsstrahlung?
    e. What materials are best for absorbing beta radiation?

EXPERIMENTAL: SAFETY

1. Your duty as safety officer is to monitor all areas, equipment, and personnel in the laboratory for radioactive contamination due to spills or other incidents. All spills will be immediately reported to you, and you in turn will immediately report any such incident to the teacher, and aid in the cleanup procedures.
2. You will determine by use of the survey meter the dosage each person in the laboratory is receiving, and you will include this in your laboratory report.
3. Sealed planchettes containing radioisotopes will be scattered in various places in the laboratory. You will locate and mark on your laboratory map the location of these sources, and their activity at a distance of two feet.

4. You will monitor the hands, equipment, and clothing of each person before he leaves the laboratory. No one is permitted to leave the area without your permission. You will be in charge of all decontamination.

5. Related questions:

   a. What is the maximum permissible weekly dose (mpd)?

   b. How long would each person be allowed to work in the lab before receiving his mpd?

   c. What are the two ways to stop radiation?

   d. Discuss alpha particle shielding.

   e. Discuss beta particle shielding.

   f. Discuss gamma ray shielding.

   g. How are radioactive spills handled?

EXPERIMENTAL: BIOLOGICAL APPLICATIONS

Each one of you will be expected to undertake one experiment showing a biological application of radioisotopes. Submit a report describing exactly what you have decided to do, your preliminary research to gain information, your procedures in detail, and your safety precautions.

The approval of the teacher is necessary before you undertake any part of your experiment.

A detailed report of your work will be handed in for grades.

POSSIBLE BIOLOGICAL PROJECTS

1. The Diffusion of Fe^{59} in the Tissues of the Rat.
2. A study of the Uptake of I^{131} in the Thyroid Gland of the Rat.
3. Fertilizer Uptake in Plants.
4. Effects of X-Radiation on Seed Germination.
5. Production of Mutations by X-Rays.
6. The Incorporation of $C^{14}O_2$ into Sugars by Photosynthesis.
7. Biological Half-Life.
8. Fertilizer Uptake in Plants.
9. The Absorption of Ca^{45} by Bone.
10. A Radioactive Study of Osmosis.
11. The Tagging of Erythrocytes with Fe^{59}.
12. Assimilation of an Isotope in Laboratory Animals.
13. Uptake of P^{32} and S^{35} by Bacteria or Yeast.
14. Sterilization of Drosophila with X-Radiation.
15. Ecological Studies of "Tagged" Insects.
16. Skeletal Autoradiography.
17. Translocation of Newly Synthesized Carbohydrates in Plants.
18. Autoradiography of Biological Specimens.
19. The Uptake of Ca^{45} by Bone.
20. Determination of Blood Volume of an Organism by Isotopic Dilution.
21. Any other project you might select, if approved.

The foregoing material is merely a preliminary guide in what is believed to be a pioneering effort to introduce a course of this type into the high school curriculum, thus making it available to high ability students who plan to make the sciences their life work. With the production of texts keyed to this type of course, and with the accumulation of new knowledge in this field, the course content will change; some material will undoubtedly be added, while some will just as certainly be deleted in the light of new knowledge.

X AUDIO VISUAL AIDS

FILMS FOR NUCLEAR SCIENCE

TITLE	TIME (MIN)
A IS FOR ATOM	15
LIVING WITH RADIATION	28
THE ATOM AND YOU	16
MEDICINE	10
AGRICULTURE, INDUSTRY AND POWER	20
ATOMIC FURNACES	20
ATOM SMASHING	12.5
THE ATOMIC GREENHOUSE	12.5
TAGGING THE ATOM	12.5
THE ATOMIC ZOO	12.5
THE ATOMIC PHARMACY	12.5
THE ATOMIC ALCHEMIST	12.5
THE MASTER SLAVE	12.5
THE RIDDLE OF PHOTOSYNTHESIS	12.6
ATOMS FOR HEALTH	12.5
NUCLEAR REACTORS FOR RESEARCH	15
UNLOCKING THE ATOM	11.5
OPERATION IVY	28
OPERATION SANDSTONE	18

TITLE	TIME (MIN)
OPERATIONS CROSSROADS	27
THE MAGNETIC BOTTLE	12.5

Other films are listed at the conclusion of each unit of the course of study.

The films are obtained from:

Beatrice Martinelli
Public Information Service
U.S. Atomic Energy Commission
New York Operations Office
376 Hudson Street
New York, New York 10014

Telephone: 212-489-1234

Film Catalogues may be obtained from:

Audio-Visual Branch
Division of Public Information
U. S. Atomic Energy Commission
Washington, D. C. 20545

A series of filmstrips for nuclear science has been prepared by:

Radiation Science Seminar
John W. Sulcoski, Director
80 N. Washington Street
Wilkes-Barre, Pennsylvania 18701

These shall be distributed at a later date, but any teacher desiring to consider their use may obtain information by writing to Mr. Sulcoski.

XI PHYSICAL CONSTANTS AND EQUIVALENTS

Quantity	Symbol	Value
1. Velocity of Light	C	2.998×10^{10} cm sec^{-1}
2. Avogadro Number	N	6.025×10^{23} molecules $mole^{-1}$
3. Angstrom Unit	$\overset{o}{A}$	10^{-8} cm
4. Planck's Constant	h	6.625×10^{-27} erg-sec
5. Curie	C	3.7×10^{10} disintegrations sec^{-1}
6. Millicurie	MC	3.7×10^{7} disintegrations sec^{-1}
7. Microcurie	MC	3.7×10^{4} disintegrations sec^{-1}
8. Micro micro Curie	MMC	3.7×10^{-2} disintegrations sec^{-1}
9. Mass of an Electron	e^-, B^-	9.11×10^{-28} gm or 5.5×10^{-4} amu
10. Mass of an Alpha Particle	^4_2a	6.6×10^{-24} gm or 4.002777 amu
11. Mass of a Neutron	$_0n^1$	1.67×10^{-24} or 1.008982 amu
12. Mass of a Proton	^1_1p	1.67×10^{-24} or 1.008142 amu
13. Atomic Mass Unit	amu	1.65×10^{-24} gm or 931 Mev
14. Roentgen	R	83 ergs gm^{-1} or 1 esu cc^{-1} (air) or 1.6×10^2 ion pairs / gm
15. Roentgen Equivalent Man	REM	83 ergs/gm^{-1} (soft tissue)
16. Barn	σ	$10\text{-}24$ cm^2
17. Coulomb	Q	3×10^9 esu

Quantity	Symbol	Value
18. Nuclear Density	-	10^{14} gm/cc or 10^{8} Tons/cc
19. Nuclear Size	-	10^{-12} to 10^{-13} cm
20. Median Lethal Dose	LD50	400 R
21. Million Electron Volts	Mev	10^{6} ev or 1.6 X 10^{6} ergs
22. Electron Volt	ev	1.6 X 10^{-19} joule or 1.6 X 10^{-12} erg
23. Year	-	5.25 X 10^{5} min. 3.15 X 10^{7} sec
24. Day	-	1.44 X 10^{3} min. or 8.64 X 10^{4} sec

CHARACTERISTICS OF COMMON RADIOISOTOPES

Radioisotope	Half-Life	Beta Energy (MEV)	Gamma Energies (MEV)
Calcium-45	160 days	0.254	None
Carbon-14	5,600 years	0.155	None
Chlorine-36	3.1X10^{5} years	0.714	None
Cobalt-60	5.2 years	0.306	1.17, 1.33
Copper-64	12.8 hours	0.571 (B^-), 0.657 (B^+)	1.34
Gold-198	2.7 days	0.29, 0.97	0.411 to 1.09
Hydrogen-3	12.26 years	0.01795	None

Radioisotope	Half-Life	Beta Energy (MEV)	Gamma Energies (MEV)
Iodine-131	8.05 days	0.250 to 0.815	0.080 to 0.722
Iron-59	2.9 days	0.271, 0.462, 1.560	0.191, 1.098, 1.289
Nickel-63	80 years	0.067	None
Phosphorus-32	14.5 days	1.701	None
Potassium-42	12.5 hours	2.04, 3.53	1.51
Sodium-22	2.6 years	0.54 (B^+)	1.28
Strontium-90	28 years	0.61	None
Sulfur-35	87 days	0.167	None
Zinc-65	245 days	0.325 (B^+)	1.12

XII TEACHING AIDS

TEXTS

1. Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., 1958.

2. Heckman, H. & P. W. Starring, Nuclear Physics and the Fundamental Particles, Holt, Rinehart & Winston, 1963.

3. Hermias, M. & M. Joecile, Radioactivity: Fundamentals and Experiments, Holt, Rinehart & Winston, 1963.

REFERENCES

1. Chase, G. D., Radioisotope Methodology, Burgess, 1959.

2. Friedlander & Kennedy, Nuclear and Radiochemistry, John Wiley & Sons, 1955.

3. Humphreys & Breinger, Atomic Physics, Harper Bros., 1950.

4. U. S. Dept. of Health, Education & Welfare, Radiological Health Handbook, U. S. Government Printing Office, 1960.

5. R.C.A. Service Co., Atomic Radiation, R.C.A., Camden, N.J., 1957.

6. Sullivan, Wm. H., Trilinear Chart of the Nuclides, Oak Ridge National Laboratory.

FILMS

The films listed may be procured on a loan basis from:

Director, Public Information Service
U. S. Atomic Energy Commission

New York Operations Office
70 Columbus Avenue
New York 23, N. Y.

CHARTS

1. Periodic Table of the Elements, Cenco
2. General Electric Chart of the Nuclides, Knolls Atomic Power Laboratory
3. Isotope Chart, Dr. te Neues & Co., Kempen, W. Germany
4. Spectrum Analysis Chart, Cenco

XIII BIBLIOGRAPHY

1. Asbersold and Hutton Procurement and Use of Radioisotopes Washington, D.C. U.S. Atomic Energy Commission September, 1958

2. American Institute of Biological Sciences Radiation Biology Institute Newsletter Washington, D.C., Vol. 1 No. 1, July 1960

3. Board of Education, City of New York, High School Division Report of Meeting to Consider the Safe Handling of Radioisotopes I^{131} and P^{32} in Ten Microcurie Lots. New York February 6, 1953, revised October, 1958.

4. Brinkerhoff et al. Exploring Physics New York Harcourt, Brace & Co., 1959.

5. Chase, Grafton B. Radioisotope Methodology, Minneapolis, Minn., Burgess Publishing Co., 1959.

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7. Federal Register Title, Part 30, Volume 21, Part 6 Washington, D. C., January 11, 1956.

8. Friedlander and Kennedy Nuclear and Radiochemistry New York John Wiley and Sons, Fourth Printing, 1960.

9. Glasstone, Samuel Sourcebook on Atomic Energy New York, D. Van Nostrand Co., Third Edition, 1967.

10. Kamen, Martin D. Isotopic Tracers in Biology New York Academic Press, 1957.

11. Lapp and Andrews Nuclear Radiation Physics New York Prentice-Hall Inc., 1954.

12. Miner, Shackelton and Watson, Teaching with Radioisotopes, Washington, D.C., U. S. Atomic Energy Commission, 1959.

13. Nuclear Chicago Corporation Radioisotope Experiments for the Chemistry Curriculum, Chicago, Nuclear Chicago Corp., 1960.

14. R.C.A. Service Company Atomic Radiation: Theory, Biological Hazards, Safety Measures, Treatment of Injuries, Camden, New Jersey, R.C.A. Service Company, 1957.

15. Schenburg, Samuel, Laboratory Experiments with Radioisotopes for High School Science Demonstrations, Washington, D.C., U. S. Atomic Energy Commission, 1958.

16. Semat, Henry, Introduction to Atomic Physics, New York, Rinehart and Co., 1946.

17. Steinberg, E.P., Interpretation of Counting Data, Washington, D.C., U. S. Department of Commerce, 1956.

18. United States Atomic Energy Commission, Radioisotopes in Science and Industry, Washington, D.C., U. S. Atomic Energy Commission, 1959.

19. United State Department of Commerce, Safe Handling of Radioisotopes; Handbook 42, Washington, D.C., U. S. Department of Commerce, National Bureau of Standards, September, 1959.

XIV METHODS OF INSTRUCTION

The methods used in any course will, of course, depend upon the teacher.

Some subject areas, such as particle accelerators, may be best covered by lecture and class discussion, due to the complexity of the available texts. Glasstone is recommended as a general text, since its coverage is rather extensive, and the literary style is quite readable.

The use of study guides keyed to the basic text have been shown to work well. These question sheets guide the student's reading and study, making it possible to delete extraneous material and to emphasize that which is considered important. An assignment on these guides will serve as a preparation for lecture and discussion, insuring as much as possible homogeneity of preparation and information throughout the class. These guide sheets plus the student's class notes provide excellent review facilities at the end of a unit or at the end of the year.

Care must be exercised that the student does not limit himself only to the study guide questions, but that he be required to perform extra reading assignments and to solve extra problem sets, thus attempting to insure a broader coverage of the subject matter than that afforded by the guide alone.